ACADEMIC VORTEX

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CONTENTS


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Preface

This book is about my journey through and view of Indian Institute of Science both as student (Masters and Doctoral for seven years) and a faculty member (for thirty four years) and another fifteen years of aperiodic visit to “my” laboratory CGPL (combustion and Gasification Laboratory) – things I learnt, joy and pain in new research and development, setting an agenda for international recognition for the laboratory, the joy of teaching, interaction with distinguished faculty and administrators both within and outside of IISc. It is more about people, some very visible and others in the backyard, all responsible for the aura of Indian Institute of Science. It is set out in a framework to ensure readability for a wider community. It is also my view of the academic world through an “IISc lens”.

The title is “Academic vortex”. It is composed of two important science and technology segments all involving combustion – aerospace and biomass (really solid fuel, because coal can be included) based clean combustion via complete or partial gasification. Apart from academic research and teaching, I had deep involvement with select DRDO laboratories and ISRO in the development of the missiles and the launch vehicles in the area of propulsion and combustion. This was indeed a fulfilling experience for me and useful to these institutions as I have understood. This interaction led to the books of significance (I tend to believe) in these areas and drew richly from the interactions. I spent considerable time on biomass energy related research, technology development, transfer and field related activities - with MNRE and industries in India and overseas. These have resulted in a book and a range of publications. I have had some interaction with media over a time that caused ripples. All these find an expression in this book.

At the Institute, I also spent time on administration in unusual ways – trying to introduce computerization to admission processes in the first stage and into financial services of the Institute in the second phase. For a few years, I was the Chairman of Aerospace engineering, Secretary, Karnataka State Council for Science and Technology (KSCST), Chairman, Centre for sponsored Schemes and Projects (CSSP) after being the Chairman of Centre for Scientific and Industrial Consultancy (CSIC) for some years. All these contributed to my deeper understanding of the Institute. During my stay at the Institute, I worked with five directors and interacted administratively with many chairmen of the departments and many other academics with whom I would discuss their area of research and technology innovation wanting to figure out what and how they do, what they do, much in the sense Richard Hamming has described in “you and your research”.

This book in its draft mode had a title - Did it make a difference – to whom – me?, the laboratory that both absorbed me and released me?, research students I supervised?, students I taught? to IISc, to others I interacted with at ISRO, DRDO and MNRE largely? and many I interacted with some on the international scene. Obviously, I have views – considered normally biased in my favour – but the benefit of having received critical observations, both direct and indirect would perhaps be seen in the writing.

Living at IISc has shaped my life – through friends from my master's course who continued on beyond as faculty, teachers who taught courses and allowed learning of what and how to navigate through complex academic milieu. I have brought out stories about how an Institute shapes a person and how a person can provide shape to the Institute.

What is the nature of readership of this book would be an important question to answer. Academics who wish to appreciate what efforts are required for technology development within an academic environment devoted to research as also the technology transfer related aspects would benefit by reading chapters 5, 6 and 10. What I think of publications may be of universal interest and is found in chapter 7. Those who wish to know how distinguished directors and academics were interacted with may like to see chapters 11 and 12. In the list of people with whom I had interacted over my life, Prof. Satish Dhawan, Prof. A Ramachandran, Prof. R Narasimha and Dr. A. P. J. Abdul Kalām are no more with us.

What I have thought of as contributions from various directors of IISc is outlined in chapter 11. Can consultancy projects also help identify useful research problems can be gleaned from chapter 8. Those who have some liking towards rockets and missiles and how the interactions took place ISRO and DRDO laboratories might like to read chapters 13 and 14. I have had interactions with media in a special sort of way. This is set out in chapter 16. I have had some difficult questions posed to me at times. The questions and responses are found in chapter 17. What did my students do after they got their Ph. D is set out in chapter 18. Chapter 19 carries pictures from academic life involving students and associates. A few of the inhabitants of CGPL for several years or more have put together what they achieved when they stayed at the laboratory and what it meant to them subsequently in Chapter 20. My view of life as I saw towards later part of my life is set out in chapter 21. My recommendation is that the various sections outlined in the content can be reviewed first and the choice of what to browse through first can be made. There are several places with technical writing that can be given a quick pass-through without loss of the overall perception.

Those who wish to know more about some technical details and scientific publications can visit the webpage: www.hsmukunda.in.

I had requested several former colleagues and friends to examine the draft of the book and offer me suggestions. I have received valuable observations and suggestions for change from Prof. A. K. Lahiri (metallurgy department), Prof. Gandhi (chemical engineering department), Dr. A Subhananda Rao, and Mr. P. Venugopalan (both of DRDO), Prof. P. A. Ramakrishna, Prof. Varun Shivakumar, Dr. G. Sridhar, Dr. R. N. Narahari (contributors to chapter 20), Dr. T. S. Channesh (Director, Centre for Public Understanding of Science) and Dr. N K S Rajan.

Dr. G. Sridhar, in addition, put in efforts to collate and review the comments and suggestions from various colleagues and offer final suggestions for modifications. I am indeed grateful to all of them for their painstaking efforts in providing me with valuable inputs for modification/correction.

BEFORE THE DAWN

Born in a town (K. R. Nagar, 40 km from Mysore) in Jan 1944 and living in a village (Gavadagere between K. R. Nagar and Hunsur) till 1948, shifted to the town, Hunsur because of transfers in education department that my father (a teacher in the middle school) was to go through. We lived in Hunsur for nine years including the three years (1954-1957) for my high school. I was tutored in English by my father in my middle school career. The environment of the town was essentially one of subsistence mode with only minor indulgence in exciting academic or cultural affairs. The pre-university course (1957-58) was a fast passage through at Sharada vilas college in Mysore and then the engineering college (1958-1963) - National

Institute of Engineering. The environment in Mysore was much broader, but my attention was directed to academic matters related to course largely. For reasons, not known to me, I seemed interested in doing chemistry as primary subject going through B.Sc and M.Sc as the first alternate. But peer group advice from family and others was in favour of engineering. The prevailing wind was in favour of mechanical/electrical engineering and I chose mechanical stream, mostly because, electrical engineering had many abstract ideas, but mechanical items were downright visible (!). The teaching in the engineering college like in high school was traditionally good in the same sense. Through the five years where in one of classmates, Mr. Prabhakara Rao and me alternated in getting ranks, the creativity aspect and sharpening the skills needing deeper thinking were always given a go by. I remember many teachers, but the most respected one was Prof. Narasimha Iyengar who came in very well-dressed manner and taught Mathematics with measured words. I can recall him standing on the dais even now. Of course, the more (may be the most) popular teacher was Prof. Aprameya who taught us drafting skills, including free hand sketching. Batchelor in Engineering completed in 1963 led me to the aeronautical engineering at Indian Institute of Science.....

1.1. IISc and .....

My first encounter with Indian Institute of Science (IISc) was some time in December 1962, a year before my graduation, at which time I was at Bangalore for laboratory work in mechanical engineering (my college, National Institute of engineering, Mysore, had not acquired these facilities yet). A friend of mine brought me to IISc to meet up with his relative in Aeronautical Engineering. I was amazed and pleased to see select group of people working till later part of the day well into the night even though the rest of place was locked up and looked deserted. Having had some bad experience during industrial training in the railway workshop at Mysore, I had “decided”, I would never join an industry demanding fixed timings (!) and would only join a place that allowed freedom to work away as much as needed any time desired. I simply fell in love with the Institute and I intended pursuing the master’s course here almost instinctively. The only place I applied for was Institute with Aeronautical Engineering as the first option and in retrospect, I have often wondered about this foolish bravado for not applying to any other place. It turned out that I got direct admission (admission based on past performance - within the first three ranks in the examinations) without an interview. I have again wondered whether I would have been accepted at all if I have had to face an interview committee. I joined the Institute for M. E. in 1963.

There were two streams in Master’s course - aerodynamics/ fluid mechanics and structures. This meant that the projects that would take would be in this stream. Otherwise, all classes would be the same. All of us 25 students were expected to learn all things (!). There seems to have been undercurrent of wanting “good” students to join structures - for projects. We were well aware of this. I and S. M. Deshpande seemed to have matching enthusiasm and inspiration that we uncovered in the first few days of our joining IISc and opted to join Aerodynamics stream. Mr. Prabhakara Rao from NIE also joined the course and he continued to be a classmate and took the aerodynamics stream. Most of our teachers were quite distinguished.

Academic Vortex

During the time I was pursuing my Ph. D., the department had a fair complement of excellent research students and particularly in fluid flows. Most of them were students of Prof. R Narasimha, Prof. M A Badrinarayan and Prof S. Dhawan. All of them were very active and my most enjoyable moments would be when we got together (Prof. S. M. Deshpande, my class mate in ME course and V. Ramjee, a research student of Prof. MAB) and talked about science, India and its problems and almost anything under the sun very intensely. Amongst the students, Dr. T. S. Prahlad and Dr. S. Vasantha went on to become directors of NAL, CSIR and SHAR centre, ISRO respectively. Others like Prof. A. Prabhu and Prof. M. R. Ananthasayanam became faculty at IISc and as expected, everybody worked through at IISc till retirement.

During this period several of us would get together in Deshpande's hostel room (A-3, which he shared with one of other classmates R N Burbure) close to the dining hall later in the evenings and chat about everything under the sun - a kind of tension release mechanism, I guess. During the last semester when we were truly exhausted because of the course load (we had to undergo the equivalent of 96 credits), that we used to make a calendar and keep deleting the days before the end!

By the time we joined, Prof. Satish Dhawan had already become director and was not teaching courses (sadly, for us). A curious thing took place when we got the time tables for the first semester. It was written inside the box SD indicating the instructor for the course. We got excited that director is going to teach the course. We uncovered that the excitement was short lived since it turned out that it referred to Prof. Somayajulu Durvasula who taught us structural vibrations. One of the most popular teachers was Prof. C. V. Joga Rao who was somewhat universally admired by all students. I was in disagreement with this admiration since I found that his lectures were quite dull on the technical aspects. He taught from his notes that did not seem to have changed from quite some time. Also, connectivity with reality seemed quite low even in this course as also in most courses. This was partly because there were no projects of significance on aeronautical development and demand for true understanding was not in great demand! There were also many moments of challenge in understanding things but the passage through the course was not as fulfilling as I thought it would be. Prof. Roddam Narasimha taught us basic fluid flows and asymptotic techniques. The course on asymptotic techniques, a subject that was undergoing development was very valuable. Prof. A. K. Rao who appeared very bright and sharp in conversations did not take any formal course. Prof. M. A. Badrinarayanan taught turbulent flows and the teaching was as chaotic as turbulence. He would not hesitate creating confusion, even though when quizzed he could not be swayed from a deeper correct point! We were taught Mathematics also in a special way. The Applied mathematics department was headed by a famous professor, Prof. P. L. Bhatnagar of BGK model fame (Bhatnagar-Gross-Krook mode in low density flows) and he taught us specially. It was clear he loved Mathematics and wanted to share it with students. Attending his classes was thrilling because we could see a senior person so much in love with what he was teaching.

Finishing up the masters in 1965, pursued Ph. D with Prof. V. K Jain and Prof S. Dhawan as the supervisors and completed it in 1970. Joining as a lecturer in 1969 in an opportunity that got created due to demand of faculty in newer areas to cope with the novel defence sponsored program on rockets and missiles, I continued till retirement at the Institute except for a two-year stint at NASA Langley Research Center at Hampton, Virginia in USA (1987-1989) and several brief visits to other countries for conferences or as a part of some delegation.

1.2. What all did I learn

While at the end of my undergraduate education, I did not know what I did not know, at the end of Master's course, I came to know largely what all I did not know and it was not small - not information, that I knew reasonably well, but the processes of inquiry! To fill the black holes in my understanding, it took over ten years and of course, in some way it is continuing even today. I have never felt far from being a student, even now. Over a period, I have learnt a reasonable amount - because I learnt "by surely knowing a little of whatever stuff that be, I can derive a whole lot of other things". I also have liked Sherlock Holmes's answer to what he knows and what he does not. He stated (my words): I do not know about stars and all the rest, but I know how to distinguish between a hundred and forty different cigarettes from the ash that I can smell - because this is what I need to know. It is not what you do not know that always matters because it is always an infinity. But what you know for sure is very important even if it is small. I can do several things attributed to Richard Feynman - like obtaining approximate values of square roots, cube roots or other arbitrary roots of numbers either in my mind mostly or on the back of an envelope and I feel challenged to examine difficult integrals, differential equations using approximate methods - inspired by Richard Hamming in his book on numerical analysis and Bender and Orzag in their book, Advanced mathematical methods for scientists and engineers. On these aspects that I developed interest over a period of time, there was no local inspiration or role model (meaning at IISc). I also have liked the adage by Richard Feynman: you can say you know when the same problem posed under different garbs can be traced back to the original problem of which you know (the solution as well). On this aspect I did work hard by reading several pieces of research relevant even weakly so to gain “surrounding knowledge”. In fact, I concluded that the difference between the speech of a man of knowledge and any other person is that when a man of knowledge speaks, it is transparent that he is expressing only a fraction of the stuff he is aware of on the specific topic being discussed; the part itself is significant whereas most other people may be speaking beyond or just about at their level of understanding and you can virtually see through them.

Andaman Gasifier Team
After Installation

THE VISION AND THE EARLY STRUGGLE

2.1. The vision

Aeronautics in the sixties and the seventies appeared dismal with no development projects being taken up and a large number of paper exercises on the design of fighters being carried out with the Government or Air force supposedly stating that since HAL had no experience in advanced technology it would be difficult to support such a project. This got repeated several times and the joke was that every head of HAL who happened to be a senior person from air force took such a position to enable him to buy nice equipment from overseas and a better prospect for himself (to become the next air chief). It was clear if we had to be intellectually alive and be relevant (particularly so in Engineering) that I suppose would be the aspiration of any academic, we had to think of strategies of achieving this objective. It was also a peculiar period when Ph. D from abroad (that meant usually, USA) was thought superior to Ph. D from India. Also, no visionary outlook seemed available from the near surroundings. I remember one event of this period of despondency.

I had been working on a set of ideas on a class of propulsion systems called hybrid rockets that appeared very relevant to India as it was a safe, robust, well performing and a very low-cost system. To a few friends, I stated somewhat wistfully, can't we do something to progress some special area unique to us (but relevant to others as well) that demands that scientists from overseas come and learn here much like it happened in the past at Nalanda and Takshashila. A few colleagues around me looked at me peculiarly and brought me back to reality. As it turned out, of the two major activities that I was instrumental in initiating, the subject of hybrid rockets did not attract the appropriate agency subsequent to ten years of effort that resulted only in publications, Ph. D for a student and occasional sporadic interest by several other agencies, but the subject of thermal conversion of solid fuels, particularly biomass has resulted in a situation that was reminiscent of Nalanda. Many distinguished scientists and other professional agencies visited our laboratory and we were instrumental in providing the inputs on the foundations of thermochemical conversion of biomass.

At the court meeting of the institute that happens in the month of March annually, there is a "court" lunch followed by the meeting. In the year 1981, at such a lunch, I was met by a senior colleague, Prof. Amulya K. N. Reddy who was leading a centre for the Application of Science and Technology for Rural Applications (ASTRA) and asked if I could look at a technology called “gasification of solid fuels” by which process it was possible to run diesel engines to generate electricity. His idea was that India had about 3 million diesel engine pump-sets for water lifting and it would be desirable to replace as much diesel as possible by using the gasifiers. His outlook was that this would make a tremendous difference to the oil import and make the rural operations less dependent on diesel with a continuing upward trend in its price. Impressed with these thoughts, I discussed the subject with Dr. U Shrinivasa (who subsequently chose to look at biodiesel seriously at the department of Mechanical engineering) and we started working on the subject with a grant from the Karnataka State Council for Science and Technology (KSCST). By this time, I had a reasonable understanding of the field of combustion, but mostly of liquid and gaseous fuels but very little of solid fuels. I thought through for myself that as an “expert” in combustion, if I was posed questions on how biomass would burn and could I estimate the rate of combustion, etc, was I in a position to deal with the issues confidently. I came to a conclusion that it was clearly “No”, was ashamed of myself that I knew little on a subject that is so much more native than what I had looked at till then. This became therefore, a serious thought, namely, I should understand the subject and get mastery over it to whatever extent possible.

Since this was not the primary subject of interest for western science in the same sense that would of interest to developing countries, it was clear that the subject was a green area and any tracks that may get created by my efforts may have lasting significance. All the aerospace stuff would provide accompaniment to this effort and I discovered that biomass based clean combustion science and development was more challenging than “rocket science”. In a way this was the vision that I had set up for myself.

2.2. The initial struggle

The area of combustion or reacting flows was very new in the department. Prof. V. K. Jain who was the student of Prof. D. B. Spalding was recruited in Prof. Dhawan’s early period of directorship. He taught us combustion as a course in M. E. We had some difficulty in following him in the course. Even during the period when course was going on, S. M. Deshpande and myself had decided to join the department for research. My own M. E. thesis was done with Prof. G. N. Venkataramana Rao and I cannot say much about what I did. When I finished M. E. the plan was to choose the supervisor. Deshpande had done a project with Prof. Narasimha and he requested Prof. Narasimha to take him as a research student as well. Of course, by that time he had several students working for Ph. D. Therefore, I had to choose another professor. Since I wanted to move on from classical fluid mechanics and wanted to do something interesting, I chose combustion with Prof. V. K. Jain. Since, I also wanted to do combustion in fluid flows, I wanted one additional supervisor in fluid flows. I requested Prof. Dhawan to be the co-supervisor and assured him that I would get to him periodically and will not bother him more frequently. He agreed. That is how I got two supervisors at that time. Prof. Jain gave me a paper written by Prof. D. B. Spalding and told me that if I did work in that direction, I would be able to do my Ph. D. While learning combustion, several doubts would arise and getting back to Prof. V. K. Jain turned out to not very profitable. The learning of the subject was largely by intense self-reading and discussions with co-students like N. Ramani who joined a year later, and A. G. Marathe who joined even later. This self-learning that got imposed on me proved to be of great benefit in the long run since thinking through intricate new issues could be accomplished with much less external input bringing greater confidence in me of other academics and industries. Mr. Ramani got his Ph. D, joined Indian Satellite Applications Centre (ISAC), Bangalore in areas related to computing for which he was justly famous at the Institute. So many research students used to make a bee line to our laboratory to meet with him (I and he were sharing a room at the Rockets and Missiles laboratory building) and find answers to why the computer was throwing out their program with some computer bug like an infinity somewhere, etc. Invariably, he would take interest and resolve their problems. He was also so popular that I used to joke with him saying that his mean free path was about as meter! Mr. Marathe finished his Ph. D and joined the mechanical engineering department to work in the area of turbo-machinery. Unfortunately, for no fault of Dr. A. G. Marathe, Prof Soundaranayagam cold-shouldered him and the collaboration simply did not work out. Several years later he moved to the Aerospace engineering department of IIT Bombay which was where he completed his academic innings.

At the steps of the river Cauvery, HSM,PJP, Dr. Dhussa,Dr. Rajavanshi……

RESEARCH DIRECTIONS

3.1. One-dimensional flames - diffusion and premixed

In the late-nineteen sixties when I worked for my Ph. D on ignition-extinction problems in laminar unmixed flames, solving problems in combustion meant for us in India solving ordinary differential equations with single step reaction kinetics. An era when understanding combustion process was in infant stages with high activation energy asymptotics considered highly respectable, pursuing analytical solutions was not out of vogue. Checking calculations meant use of merchant calculating machines. Use of similarity principles, treating stagnation point configuration that allowed such simplification, making predictions that would be more qualitative because kinetics is not founded in realism was the order of the day. Even such research was applauded! It was clear to me that if predictions on ignition-extinction problems had to derive respectability so as others like flame speed or the burning velocity, a fundamental combustion parameter, there was no escape from full chemistry calculations. Full chemistry description was getting refined through the seventies and therefore it would be ideal to work on full chemistry problems. Premixed flames appeared more appropriate since diffusion flames are nearly independent of chemistry for the rate of combustion - it would depend on chemistry only for ignition and extinction. From this, started the code development for premixed flames that adopted a more straight forward unsteady approach than the more cumbersome steady state approach used in the USA. Several Ph. D theses were completed using this code meant for full chemistry and one outstanding contribution was a definitive conclusion that adiabatic flames do not have a flammability limit (K. N. Lakshmisha's and Gajendra Goel's Ph. D theses). Predicting the flammability limits implied invoking an irreducible minimum radiative heat loss. Dealing with spherical flames (D. P. Mishra's Ph. D. thesis) that was a subject of study for a few years could still be ordinary differential equation based. Much was learnt about how heat release occurred in a premixed flame, how stretch effects had complex relation with chemistry, etc.

3.2. Two-dimensional flames

Time came to move on to two-dimensional (2-D) issues. My colleague, Prof P. J. Paul wrote a 2-D reactive fluid dynamic code (called RCFD – Reactive computational fluid dynamics) and the first case that was tested was stretch effects on a Bunsen flame. Since there was competition for work in this area, application for this code was found in the area of Ammonium Perchlorate (AP) - Polymer sandwich propellant combustion that required tracking a burning surface and observing the variation in combustion process due to the distortion in the surface. This research forming the thesis of P. A. Ramakrishna (currently Professor in Aerospace Engineering, IIT Madras) had a test of confidence in CFD (computational fluid dynamics). Solving two momentum equations with energy and species conservation equations using 3-step chemistry with along with a pyrolysis law for AP surface decomposition and unsteady condensed phase were the substance of the problem. Computer solutions with the known chemistry parameters from the literature always went chaotic. Code was suspected. This suspicion proved incorrect and the non-converging nature of the solution persisted. After much soul searching, the simplified problem of AP combustion was run in 2-D mode. Non-convergence of solution persisted. It was clear that the non-convergence of the full problem must have been related to some instability. Linear instability solutions from literature were then examined; these clearly showed that for the chosen parameters that were standard in the literature for over thirty years and used by all stalwarts, the solution of the full unsteady problem was unstable and this feature had bypassed all the stalwarts because they never treated the problem fully and when a few treated the problem fully, did not analyse what they found clearly, and bent other features to somehow show a steady result - great science by stalwarts!. Then onwards, the pathway for Ramakrishna was clear but not necessarily bright. The physically observed steady combustion process implied that the chosen parametric values for a crucial parameter, namely, the activation energy for pyrolysis was incorrect. Efforts were put in to determine this parameter consistent with other experiments and the observations of AP and AP-sandwich combustion. A paper was written and sent off to a journal. One reviewer, from what we deduced, was a stalwart and he was highly caustic arguing how a new study that departed in its choice of parameter from those of the stalwarts could be correct at all! It then took two years, spirited defence at an international conference by Ramakrishna, showing up the presence of this instability in others' calculations not adequately recognized, and arguments with several scientists to remove the blocks in the minds of a few scientists and the editor of a journal for the important finding to see the light of the day. The central message from this struggle is that it is important to have faith in CFD for oneself, that too of a substantive nature for ensuring that others respect your findings.

3.3. On faith in CFD

On the subject of faith in CFD*, I must relate my experience in 2005. I attended an important review meeting of a major project as a member. This meeting was chaired by a very distinguished, accomplished head of a major national project with CFD-India's who-is-who all being there as members. Many external flow simulations were presented with some good comparisons and some not-too-good comparisons. Some noises ware made, but results were accepted broadly. There was then a presentation on experiments on air-intakes by a distinguished scientist. Till that point, the presentations showed results of calculations and experiments, but the airintake results had no comparisons with calculations. I asked how come, there are no calculations. There were responses of a bewildering kind.

[* CFD, computational fluid dynamics, was a fast-developing field through the seventies into the eighties and much development into algorithms that can compute the flow field with accuracy took place during this period. There were also discussions and making fun of the presentations as one of colourful fluid dynamics due to innovative way of presenting the flow field. However, far more careful development took place over a time in obtaining accurate flow field]

One distinguished person stated that no internal flow calculations of air intakes had been made and it is difficult! Other defences from stalwarts were that experiments showed the truth and should be trusted and the lack of calculations for air intakes was an acceptable state. I must tell you, that I was completely non-plussed, for, I had not bargained for a sudden nose-dive in the quality of appreciation among distinguished people.

The central message that I got was that CFD people doing external flow had no feel for internal flow problems - why, I do not understand. The equations are the same, the governing phenomena will have one key feature that is different - Viscous dominated features like separation, shock-boundary layer interaction issues, mixing layer-boundary layer interaction can be far more severe in internal flows and it is perhaps true to say that all the modelling aspects have not been understood. Even so, some broad features could usually be predicted well or the differences tracked down to specific features of the model. For instance, it is generally known that k-ε turbulence model does poorly in recirculating flows and flows with separation. But this would not mean all aspects of predictions would always be poor. In any case, of the several classes of experiments done, some that would be straight forward could be simulated well and reasons for poorer comparisons, if any can be tracked down. Nothing of this class could even be discussed in the meeting. This brings me to the next question:

3.4. Experiments always superior?

Should comparisons of predictions with experiments mean that experiments are always to be treated as reference for comparison. Rather, are experimental data holier than computational results. Most often the undercurrent of thinking in the mind of an average computational man is to somehow show that comparisons are good, for otherwise, people may suspect the quality of computational results. I think, if the person who has computed has taken adequate grid resolution, used the appropriate boundary conditions, the person must have confidence in the results and there should be no hesitation to begin to doubt the experimental results. One should then go ahead and examine the experimental technique, the accuracy of the measurements, back ground of the earlier work of the investigators, and aspects like that to ensure the integrity of the experimental data. This might reveal aspects to support the suspicion of the quality of experimental data. One could then bring these out into open for clear discussion. I had two experiences in this direction.

3.5 .....Briefly on erosive burning

I was studying five decades ago a problem known as erosive burning of solid propellants. I had constructed a theory and this was published. Some two decades later, I revisited the problem. Lot more data was now available on many propellants and some reviews too. The reviews seemed shallow and the data presentation technique was designed to avoid controversies even if one existed. I used some data on the same propellant by two different investigators and cast them on a single plot using non-dimensional coordinates. These showed clear differences. Then I put together lot of other data on the same plot. It looked as though the differences that were seen between vastly different propellants were no more than for the same propellant by different investigators. The conclusion was that this would be the irreducible minimum difference that one could not avoid even with best of intent. And, if so, no more experimental work need be done and all the data fitted into a single universal curve (the work published with my colleague, Prof. Paul). Perhaps one should be brave to suggest this. And many superficially minded people might even debunk this conclusion. It is only the carefully minded person that can see the gravity of the conclusion - no more experiments are needed!

3.6. Issues on lifted flames

Sometime in 2004, I had another strange experience of people wanting to avoid controversies even when they are very visible and are pointed out. One of our students Sudarshan Kumar Vatsayan (currently Dr. Sudarshan Kumar, Professor, IIT Bombay) while was working on flameless combustion was examining lifted gaseous flame data. Lifted flames have occupied the interest of combustion scientists perhaps, to an obsessively large degree. There were experimental data on the same fuel-oxidizer combination by two different authors. The experiments were extremely simple - determination of the lift height under different flow rates of fuel and oxidizer. Here again, the results of two different authors for the same fuel-oxidizer combination showed significant differences. Communication with the authors directly as well as a few others showed an unacceptable scientific attitude - “I swear by my results. I will not comment on others’ results” - truly strange. There was no way other than to publish the results as they were. They even have got published with no comment from any reviewer or other authors. We perhaps must allow time before somebody adequately brave takes up the issue. The summary of all these experiences is that we should work hard to build our own confidence in what we do - through careful checks, responding to criticisms through additional work, if necessary, or whatever it takes to be sure of oneself. By building confidence in CFD (not over-confidence), we will help the designers and sometimes the experimenters too - for, they do not usually have the privilege of seeing all the details of the flow field that CFD will provide. Experimental mapping of combusting flow is far more difficult.

SCIENCE OUTREACH

4.1 Introduction

There are two kinds of scientific work that get attention in the World. One is pure science whose connection with reality can be distant, not in just in time, but can be relationally as well. If science improves the understanding, it may help assimilating what happens in practice much better even though very little can be done to change the behaviour of the practical system. Apart from several other ways science makes sense, science can also emerge from practice. If some technology is in place and one sees defects in the behaviour, one will seek to determine what causes the issues. This part is science. However, one can ask a further question:

Can we not use science to help overcome the defect? The answer can be, Yes, it is possible. Both these classes have occurred in my academic life. The reason they occurred is because, driven from inside, I wanted to be seen relevant in pure academic arena and in engineering science to help design new approaches to combustion for practice. Both these aspects will be described here. The first part of visits to international symposia constitutes the pure science aspect. Visits to conferences in Stuttgart, Germany and Rio de Geneiro, Brazil and workshops in Indonesia, Thailand and China belong to the latter.

The fact that one is involved in scientific work can be known to others only through publications. However, all the understanding that one may have or have had cannot be set out only in publications. It would be important to communicate with other scientists of various ages and calibre to figure out where one is and what directions to take to improve oneself and enhance the outreach.

This would imply participation in conferences. The very first conference I participated in is the first national heat and mass transfer conference held at IIT Madras in 1971 December - at the time when the Indo-Pak war in Bangladesh was going on.

There were other conferences that I participated in India on various subjects related to combustion and propulsion, like the national conference on combustion. These conferences appeared too docile and meek. There was no subject of deep fundamental or technological relevance or no vigorous discussions that threw up new ideas. On the other hand, my reading the international combustion symposia showed that the subjects on which papers were written and the document containing the discussions at the end of the paper were both stimulating and worthy of contemplation. If one were sensitive, one would think when the paper was read and connected to the discussions, on some occasions the conclusion would be that the paper was written prematurely or better, not written at all. I decided that participating in these conferences would be a great virtue for my learning the combustion science and learning about the people involved in it internationally.

B. N. Raghunandan (BNR for short) had come in as a research student after completing B. Tech from IIT Bombay in 1973 completed his Ph. D in 1977 and his research problem was on the experimental and analytical studies on single droplet combustion. He had also performed experiments on polymer sphere combustion. The first conference to which we submitted a paper was in 1976 to the 16th symposium. The paper came back with one positive review and one quasi-positive review and one negative review. Unless all the three reviews were positive the paper was not accepted for oral presentation. If it were a journal, rebuttals were possible and, in all probability, the paper would have been accepted. It happened exactly this way. The same paper was submitted to the Journal, Combustion and Flame, a little afterwards where it was accepted and it has got published in 1977.

4.2. The 19th Int. Symp. Comb. at Technion, Haifa, Israel, 1982

This was the first international symposium I attended and this was also the first overseas visit. The symposium took place at Israel Institute of Technology, Technion, Haifa, Israel. In those times, finding money for international travel was difficult. Funding was received from INCOSPAR, an international organization with the help of Prof. S. Ramakrishna who had the formal position of Advisor to the Director, Prof. S. Ramaseshan (Prof. S. Dhawan had retired in 1981). This was the first visit outside India and a slightly complex one in terms of journey. I had to fly into Cairo on a Egyptian air flight, take a different El Al (Israeli) flight and on return via Cairo.

The paper was on the science of hybrid rocket combustion process written with P. J. Paul and Prof. V. K Jain.

P. J. Paul who was completing his work towards Ph. D. under the joint supervision of Prof. Jain and myself. The reviews received were unanimously positive and one of them laudatory and hence oral presentation was possible. At the conference, I heard some outstanding talks and discussions at this symposium including clash of ideas between the well-known people during the question-answer session. I enjoyed it so thoroughly that I decided that it is the Mecca of combustion science because also it was and is attended by all the leading scientists in the World and I should try and participate in it with our contributed paper accepted for oral presentation.

During this conference, I developed contacts with several people, Prof. S. Okajima, John de Ris, Dr. M. King, Prof. T. Niioka, and others. Dr. King pointed out in a discussion of my presentation that Kutataladze had studied the effects on heat transfer of injection of higher molecular components into a boundary layer. I met Academician Kutataladze in his institute at Novosibirsk, Siberia, USSR later (see chapter 12, section 12.1).

I got invited to visit the department of Aeronautical engineering and I took that opportunity to speak to Prof. Y. M. Timnat, Professor in the department in the area of Propulsion. I had read his early research on hybrids before the visit. He appeared to be gentle and easy to have conversation with unlike some of the other US counterparts who seemed wanting to project that they knew everything! He invited me for an evening dinner to his home, something that I thought was unusual. There were some others from the conference at this dinner most of whom I was unaware. I also met Dr. Gany who was perhaps of my age and we spoke about various matters. At the dinner, for the first time I ate olives (!).

Both Prof. Timnat and his wife came to Bangalore during the ISABE conference in 1992 that took place in Hotel Ashok. At my invitation, they visited our laboratory, saw around what we were doing in propulsion and combustion of solids.

At Haifa, a post-symposium trip was organized for visits to the Masada, dead sea and Jericho, supposedly one of the oldest cities going back to 12000 years. On this trip, Prof. S. Okajima and myself became good friends (you can see him in a picture in Chapter 19, photo 19.2). He showed a degree of interest in India to such an extent that I invited him to come and visit us. He had done extraordinary experimental study of zero-gravity droplet combustion along with his supervisor, Prof. Kumagai. This work was followed up later in the USA as a prelude to Space shuttle-based drop combustion tests. While this kind of experimental study would add value as test case for validating theories, and it is only of fundamental interest.

On the return flight, I arrived at Cairo in the morning. Since the flight out of Cairo to Mumbai was in the night, there was an opportunity to visit the pyramids during the day after depositing the passport. A Japanese couple and myself went on this trip organized by the tourist agency. When we returned in the evening, I was told that the flight on which I was to return got over-booked and I was to wait till next day. I was shocked because I had not expected this turn of events. It took some time and rather reluctantly acquiescing to the demand for tipping the several staff before I could board a flight the same night!

P. J. Paul, H. S. Mukunda, and V. K. Jain. Regression rates in boundary layer combustion. In Nineteenth Symposium (International) on Combustion, pages 717–729. The Combustion Institute, 1982

4.3. The 20th Int. Symp. Comb. at Ann Arbor, Michigan, USA, 1984

Following on the work on droplet combustion of liquids and synthetic polymers that BNR did, a study of literature showed that nobody had studied wood sphere combustion. Thus, it appeared natural to study the behaviour of wood spheres experimentally, analytically and computationally. The wood spheres were obtained from Channapattana, the wood toy town on Bangalore - Mysore highway and experiments were conducted in adequate detail. Combined with analysis, the matter was put together into a scientific paper and submitted for presentation at the 20th symposium (international) on combustion due to take place in August 1984 at the University of Michigan, Ann Arbor, USA. Another paper on Ammonium perchlorate (AP) pellet combustion with detailed chemistry with H. K. Narahari as a student also was sent across. Both these were accepted for presentation and publication in the proceedings. During this time, Dr. B. N. Raghunandan (BNR) had already become a faculty member at the department. At that time, we had floated an exciting project to ADE, Bangalore to deliver 6 pieces of a flying hardware that burns LPG and produces high temperature gases that heat up a perforated can which should act as an infrared tow target for missiles to do practice firings based on a new swirl combustor design. We had conducted some initial trials at the laboratory. ADE was also in touch with a company in US to procure the tow targets. We had floated the project through the centre for scientific and industrial consultancy a consultancy project since this enabled us to make use of a part of the finances for international travel. We planned over two months. Our travel along with Udups, P. J. Paul (PJP), H. K. Narahari, and BNR seemed confirmed through several financial resources including the combustion institute's waiver of registration fees and part funding of travel for myself and H. K. Narahari (because we were the authors of the papers). At this time, I induced Mr. P. Venugopalan of DRDL with whom I had a large number of interactions because of liquid rocket engine development at DRDL to attend the conference and other visits by getting the clearances from DRDO and he accomplished it. We wanted to travel to US, France and Germany during the three-week period. The conference itself was for one week - Monday to Friday and incidentally, the last paper of ours (on AP combustion) was attended by Forman Williams and Ed Price of Geogia Tech, Atlanta. The biomass combustion paper was also attended by all the big people in biomass - de Ris, Kanury Murthy, Tewarson, and Prof. Chittawadgi of IITB. I think both these talks came off well and based on the random feedback I received, I felt pleased that IISc has started etching its position in the international world of combustion science. In order to extract the best from the symposium, each of us panned out in different sessions and looked at the posters and spoke to as many researchers as we could. We would get together with some Indian-American academics at some restaurant partly to know the gossip about various matters making life part matter-of-fact and part imaginative.

After the symposium at Michigan, we visited Prof. Forman Williams at Princeton (he had moved from San Diego and after several years moved back claiming bad weather conditions in Princeton compared to San Diego) discussing combustion aspects, Prof. Ed Price in Atlanta where we discussed solid propellant combustion, then, Leeds, Birmingham in Alabama, a company that produced tow targets commercially (we did not get much out of this visit as imagined) and then, went back to New York. All the journey was made in Greyhound bus with a full week pass. We saw around in New York and left for Frankfurt, Germany. In Germany, we visited Bremen where an industry was producing Torpedo and then left for Paris. In Paris, we visited ONERA and missed visiting SNECMA that produces liquid rocket engines for ARIAN launch vehicle. At ONERA, we met Dr. Langelle and colleagues and held discussion on propellant combustion modelling. We were taken to a lunch that stretched for two hours with a variety of "smelly" cheese. From here, we left for Eindhoven in Netherlands to visit Prof. K. Krishna Prasad who was working on heat transfer in wood burning stoves (photo 19.4 in chapter 19 shows all those who visited him and his student). He had left IISc just a few years back and had settled down here. We gave a talk on biomass combustion, visited his laboratory where they were making measurements of efficiencies of wood burning stoves. We, then, went back to Frankfurt to return to India. It was one of the major trips taken by a group of academics that appeared somewhat out-of-the-World not only to faculty at IISc, but even to ourselves. This visit was a kind of break from the IISc routine and filled us with confidence that we also could be reckoned with scientists in combustion science dominated by the USA first, Europe, Japan and Australia later. China was virtually absent in these meetings.

H. K. Narahari, H.S. Mukunda and V.K. Jain, A Comprehensive Model for the Combustion of Ammonium Perchlorate, Proceedings of the 20th Symposium (International) on Combustion, pp.2073-2082, 1984.

H. S. Mukunda, P. J. Paul, U. Shrinivasa and N. K. S. Rajan, Combustion of Wood Spheres - Experiments and model Analysis, Proceedings of the 20th Symposium (International) on Combustion 1984.

This journey of five of us was so historic that it was not repeated. The lighter side of the long trip in the USA (of general interest to a reader) is set out in Appendix I.

4.3.1. Frankfurt

We arrived at Frankfurt on the 27th August at 11.55 am. Got through the immigration and customs without any issues and got located at a convenient spot and began the task of fixing up our program in Germany and competed it by 6 pm. The telephone service was not as good as in the USA but reasonable. Spoke to Mr. Soffker at MBB, Bremen and Prof. Krishna Prasad at Eindhoven and set up the programs. The journey was by train. The cost of the journey on per person basis reduced with the increase in the size of the group. The entire journey from Frankfurt, Bremen, Eindhoven (Holland), Paris costed 100 USD per person.

Left the airport to Frankfurt-ab-Main station. The trains in Germany and Holland run so much on time that they can be believed to even 30 s on a long journey. After reaching the station we walked around because the train to Bremen was at 12 midnight. We moved along the river for about an hour, took strawberry milk shake at a small shop. The whole place was quiet but had a small number of people walking around talking in mild tones. It was an evening and a beautiful scene. This phenomenon was a distinct change from that in the USA where oner could see only cars buzzing past with no people around. It was a refreshing change. The place had also some churches that appeared old and well preserved. Such a phenomenon would repeat in the European cities we saw on the train or visited. We had dinner in an Indian restaurant named Maharajah close to the Frankfurt station at 7 marks per person (about 3 USD).

4.3.2 Bremen

We left Frankfurt at 12 midnight, changed the train at Hanover at 4.30 am and arrived at Bremen at 5.30 am. Got out of the station, changed the clothes and breakfast and walked around a bit. We went then to ERNO, MBB. We were received by Dr. Soffer, and introduced to the colleagues. After a brief presentation by me, we were taken to their theatre for their side of presentation. After that we had good lunch and were shown around by their PRO. There were many interesting aspects of the work which we enjoyed listening to and we completed the visit by 1.30 pm. During the visit we were met with by Dr. Venkatesh a former student who finished Ph. D at IISc. We walked around the streets of Bremen, saw some nice places, had a cup of coffee and left for the railway station. Took the 4.30 pm train to Eindhoven and we were checked at the border for our visas and we finally reached Eindhoven on 28th itself at 10.15 pm. We were received by Prof. Krishna Prasad and put up at a hotel for 50 USD for five persons (cheap really). The next day saw us busy at scientific discussions with a special vegetarian lunch and a final vegetarian dinner at a hotel devoted specially foe vegetarian food.

4.3.3 Paris

We then left for Paris by train at 8.30 pm. Passing through Brussels and another border town of France, we were not checked for passports, but for narcotics. We finally arrived at Paris at 6 am and booked ourselves into a hotel for 6 USD per night without a special bath. In the morning at 9 am, we were driven to ONERA in their transport. We arrived at 10 am and met with Dr. Langelle our contact scientist (he did his Ph. D with Forman Williams). We spent time discussing propellant combustion and then proceeded for an elaborate lunch of seven courses with near-foul smelling cheeses as well. I could deal with only 10% of the food on thew table. We were dropped back at the hotel by the evening. In the evening, we saw the Eiffel tower and a number of beautiful parts of Paris on 30th and 31st August. We left at 11 pm by train for Frankfurt, arrived at 7 am at Frankfurt (on the 1st September 1984), roamed around and bought some items. We left for the airport by 12.05 pm and checked into the Frankfurt – Kuwait – Bombay flight at 1 pm. The flight got delayed by an hour and we actually left Europe homewards at 3 pm, arrived at Kuwait at 10 pm (local), took the flight to Bombay at 10.30 pm and arrived in Mumbai on 2nd September 1984 by 5 am. Got out of the customs at 9 am because of the loss of baggage of some of our friends. Arrived at Santacruz, booked our return journey to Bangalore and went to my sister's place, refreshed myself and returned to the airport for taking the flight to Bangalore and arriving at Bangalore at 6 pm on 2nd September 1984. In all the places we visited, if we did not stay in a hotel or a home, we would use the locker facility to place the baggage for the necessary duration.

4.4. The 21st Int. Symp. Comb. in Munich, Germany, 1986

The background to the paper presented at this symposium is as follows. In a work on liquid droplet combustion under zero-g conditions tackled in thesis of BNR it was shown that a substantial part of the discrepancies could be overcome by accounting for the variable property effects, particularly with respect to flame stand-off. Later, in the thesis of PJP it was shown that in the case of forced convection boundary layers, the burn rate dependence on fuel could be predicted only if the variable density effects of the boundary layer are properly accounted for. When the question of examining the greater validity of the idea came up in my mind, I thought that the convective boundary layers may also display the same behaviour. In the present case also, it was felt that a consistent theory which accounts for variable thermodynamic and transport properties would remove the ambiguities connected with the choice of properties at several places and so improve the quality of predictions.

This work was the master's thesis of Mr. M. Hegde who had joined as a student in 1985. The paper received very positive reviews and was accepted for presentation at the Munich symposium. Mr. Hegde had inclination towards renunciation and spirituality and seemed uninclined to continue in professional work. If he was inclined towards professional work, it would have enthused me to find money for his travel to the symposium. Anyway, PJP and myself went to attend the symposium. Mr. H. K. Narahari and Mr. Gajendra Goel joined in to make presentations of their work in the poster session (these are work-in-progress material that is generally accepted without review). In order to take benefit of the visit to Europe, we thought we will look at gasification related company. There was one company close to Amsterdam and we wrote to them as to whether we could visit them for technical discussions on gasification. They agreed. The symposium was as usual exciting and we attended all the sessions including posters. Posters also contained some exciting research and allowed better interaction with the authors. Our paper was well received and quite seriously discussed. We were able to establish the role of variable properties under different combustion conditions and convey it effectively to the researchers.

At the end of the symposium, we visited the Munich Museum of science (the picture can be seen in chapter 19 and subsequently, we went to the gasification company and held discussions. They presented us with a knife each with a comment that we may need it to scrape the deposited tar on the components! After this we went to Cologne from where we took a beautiful boat ride on the river Rhine to arrive at a station called Bingen. From here, we took a train to Frankfurt from where we took the flight back to India.

M.S. Hegde, P.J. Paul, and H.S. Mukunda, Free Convective Combustion on Vertical Surfaces - Variable Property Analysis and Experiments, Proc. 21st International Symposium on Combustion, 1986.

4.5. NASA LaRC, Hampton, VA, USA - 1987-1989

Based on my application and proposal for Senior Research Associateship at NASA Langley Research Center in 1986, and the recommendations from Prof. A. K. Rao and Prof. R. Narasimha who were my teachers during M E, I was accepted for the award of the Fellowship in early 1987. I left for the USA on 15 June 1987 and was with my family in the USA for two years till 09 June 1989 working at the computational fluid dynamics (CFD) branch of the NASA Langley Research Center (LaRC) at Hampton in Virginia. I was in the Computational fluid dynamics branch where my colleague and friend, Prof. S. M. Deshpande had spent two years much earlier. It was a wonderful time for the family and a good time for me at LaRC. I explored a new area - the scramjet combustion process meant for hypersonic vehicles apart from the work on instability in premixed flames on which I had planned my research. During my stay, I learnt much in these areas, interacted with scientists in this division as well as others, but cannot say I did outstanding work there. I was considered a combustion scientist with modelling and computational interests in high-speed combustion. Stability of premixed flames and mixing in a supersonic shear layer were the subjects I completed my studies therein. Dr. Phil Drummond was my technical supervisor in the branch. Indeed, a good person working on computational aspects of the scramjet with limited interest outside his area. There was Dr. Ajay Kumar an alumnus of IISc who became the head of the branch after a year of my stay there. During my stay, I was invited to deliver a course on elements of combustion science and the relationship to issues and problems studied at LaRC because there were several students pursuing Ph. D in computational combustion, but were treating the combustion aspect as a black box - one of kinetics with allowed arbitrary choice of the kinetic constants! I was a member of a committee that examined high speed combustion. Of course, there were aspects that were X rated (classified) and I was not as part of the discussion. There were several Indians working in the group and we had a pleasant time there.

I also learnt the excesses in research mode that should be avoided during the many interactions with scientists here as well other visiting scientists and academics. Curiously, several senior people at LaRC did not think highly of distinguished academics in combustion science. Profs. I Glassman, C K Law and a few others visited LaRC wishing to propose projects sometime in late 1988. I was present at this meeting. The way they were treated by one of the senior scientists of LaRC surprised me - their ideas for high-speed combustion were ridiculed - actually, it was also true that their understanding was far removed from reality. Even so, the intellectual life at LaRC was somewhat monochromatic - around algorithms and computation of physics of high-speed flows.

While at LaRC, one interesting and nice exhibition towards the end of 1988 was of a F117, the stealth fighter used extensively in Iraq war in 1991 that was developed in secrecy usually associated with advanced developments, but got presented on the east coast for the first time at LaRC. The most memorable part of US experience was the visit to Orlando in Florida. I had a paper to present at the Eastern section combustion meeting in clear water beach in Florida in late 1988. Using this occasion, I and Dr. K. C. Adiga formerly of IISc, but working for contractor at the office of naval research (ONR) visited with our families. After the participation at this combustion meeting, we visited the Disneyland and Orlando. So mind blowing was the Orlando visit was that I feel every child or adult who wishes to experience the wonder of a childhood should be able to experience it.

In January 1989, I attended along with Dr. Phil Drummond, the Reno conference on aerospace sciences where Prof. Dimotakis of Cal Tech and Prof. Swithenbank of Sheffield university spoke interestingly and differently. Prof. Dimotakis presented what he considered serious mixing problems in supersonic flows and a very despondent picture for the development of supersonic ramjets. Prof. Swithenbank presented a view that in a scramjet, one needs to balance the loss due to mixing with the energy release processes and based on his model of the combustion behaviour inside the combustion system, suggested that aiming at a combustion of 80 to 85% would appear optimal. The presentation by Prof. Dimotakis and interest by academic institutions on seeking research grants to study and enhance the mixing in supersonic streams seemed to me like an academic hype. I say this because even as early as in 1964, Marquardt corporation had done an experimental investigation on what appeared like a well thought strut-based combustor at Mach numbers of 2+ that had shown good performance. Twenty-five years later to claim that there are serious problems seemed too exaggerated. Further, Prof. Frank Marble from California Institute of Technology presented an important argument for natural enhanced mixing in which shock waves intersecting zones of density gradients due to hydrogen (when hydrogen is used as the fuel) or partially burned gases and air lead to the generation of greater mixing (due what is known as baro-clinique torque). Further, this complex flow with chemical heat release can be studied using computational tools in conjunction with the conservation equations for mass, momentum and energy and species and such study has actually shown good comparisons of predictions against experiments. What more, flight tests have been carried out in the last decade by NASA (USA), ISRO in India to show that good performance of scramjet engine can be obtained with typical flight Mach numbers exceeding 6.

I returned from US in June 1989. A few statements about why I did not wish to continue in the USA would be in order. At NASA Langley, I was a combustion scientist with modelling and computational interests in high-speed combustion. Stability of premixed flames and mixing in a supersonic shear layer were the subjects I studied therein. I believe I was well respected and I delivered several lectures on basic combustion science and the relationship to issues and problems studied at LaRC. There were several Indians working in the group and we had a pleasant time there. I was a member of a committee that examined high speed combustion. Of course, there were aspects that were X rated (classified) and I was not as part of the discussion. Even so, the intellectual life was somewhat monochromatic - around algorithms and computation of physics of high-speed flows.

Challenging questions and ability to pursue them at NASA had a very limited track. Back at CGPL, I was accustomed to looking at a range of scientific and technical issues during a day - gaseous, liquid and solid fuels, low speed and high speed all were a part of consideration. It was a vibrant environment with many students around. I was getting increasingly home sick. I spent considerable time talking to our colleagues at IISc on all matters. If I were to evaluate the intellectual environment at LaRC for the pursuit of new questions on combustion science, I would say that it was below par unhesitatingly. One of the scientists who visited me back at CGPL some years afterwards was surprised to note that there was a large group working on experimental, analytical and computational aspects on a variety of subjects in the laboratory and expressed his surprise to me directly.

In 1993, I expressed my view of the issues surrounding summary status high speed mixing problems, a meeting attended by many fluid dynamitists from many countries. In recent times, I have inferred that the hype has got decayed over the last decade when successful engine flights from NASA and other countries. These days there is virtually no talk on mixing issues in high-speed combustion problems showing that the exaggeration was unwarranted and if they had spent time in understanding what Marquardt corporation had done, they would have moderated their projections.

4.6. The 22nd Int. Symp. Comb. at Washington Seattle, USA, 1988

During this period, I was in the USA at Hampton. The focus of the work of K. N. Lakshmisha (now, a Professor at the Aerospace Engineering department, IISc) who was a research student at CGPL was on exploring whether a propagating one-dimensional adiabatic premixed flame has features of a flammability limit was attempted by making numerical calculations of the unsteady conservation equations using full chemistry. The code was shown to predict the burning velocity and several other known features of methane - air flame at stoichiometry first and lean conditions after that. The calculation showed fluctuations in the calculated burning velocity that disappeared when the grid was refined as also domain extension because the flame thickness could increase. By repeatedly following this procedure a steady propagating flame was captured with a low burning velocity. Continuing to decrease the leanness showed that the calculation did not break down, but kept showing very small steady propagation rate at mixture ratios much leaner than the observed limits. This meant that explanation for the limits should be sought in other aspects - three dimensionality or inevitable heat losses. The paper evoked much heated private discussion since a comparable code in the USA that was essentially a steady formalism was not able to capture the behaviour at very lean mixture ratios and as to how the unsteady code could do it, etc, etc. We inferred that it was the case of petty jealousy amongst upcoming and established researchers who think others cannot do work of their quality and need to be ignored.

I had also had a paper connected to stability of one-dimensional flames in the poster session classified as work-in-progress. The stability analysis and the calculations needed a stability analysis code and an existing code developed by another scientist at LaRC was used to obtain the results. The work was good for the rigour of analysis;

it got published later in a journal. I do not think that the study was profound for its objectives. When PJP and myself were next to the poster, Prof. Forman Williams who also had another poster close by walked in and began discussing some non-linear behaviour of combustion systems. Prof. Paul seemed to have had a complete understanding of the situation and was responding to points made and raising other points with Prof. Forman Williams. This appeared typical of PJP. He would remain silent till he would understand completely and then he would speak without any hesitation. It was very delightful for me to watch, I would say. Prof. B. N. Raghunandan was also at the symposium with another paper accepted for presentation and he came from Japan where he was on a sabbatical at the invitation of Prof. Okajima.

We used to meet in the evenings for dinner at local restaurants occasionally with some Indian Americans who have been in combustion science in the USA for a while and participate in the symposia. We would get to chat about some of their professional issues with native Americans and their life in general.

After the symposium, PJP, Lakshmisha and Gajendra Goel came to Hampton, stayed at our home for two days. Discussions on the conference and the life at Hampton and driving around to show the town were all that took place.

K. N. Lakshmisha, P.J. Paul, N.K.S. Rajan, G. Goyal and H.S. Mukunda, Behaviour of Methane-Oxygen-Nitrogen Mixtures Near Flammability Limits, Proceedings of the 22nd International Symposium on Combustion, pp 1573-1578, 1988.

4.7. The 23rd Int. Symp. Comb. at Orleans, France, 1990

This symposium had two contributed papers from us. A paper by Lakshmisha continuing on from the earlier work to predict the limits of one-dimensional flame propagation based on calculations of a nature similar to the previous one but with realistic estimates of irreducible heat losses by wall conduction and radiation was accepted for oral presentation. I had another paper I wrote with a colleague Dr. Balu Sekar from NASA LaRC on supersonic mixing layer without and with heat release. In this new study, it is first shown that most of the problems of high speed combustion with air are characterised by weak heat release. The smaller differences between mixing without and with heat release of high-speed flows in comparison to incompressible flows are argued to be due to larger enthalpy changes due to gas dynamics in comparison to heat release. It is finally suggested that problems of reduced mixing at high speeds are not severely hampered by heat release, a formal conclusion that reduced the concerns expressed by Prof. Dimotakis. This visit had myself, PJP and Lakshmisha at the symposium and we flew back after the exciting symposium week. I had come to France from the USA where I had spent a month at the institute of computer applications to science and engineering (ICASE), LaRC at the invitation of its director, Dr. Hussaini. In fact, I visited ICASE again in 1992 for a month and wrote a formal report on the status of scramjets based on information from open literature.

K. N. Lakshmisha, P. J. Paul, and H. S. Mukunda. On the flammability limit and heat loss in flames with detailed

chemistry. In Twenty-third Symposium (international) on combustion, pages 433–440. The Combustion Institute, 1990.

Sekar, B, and H. S. Mukunda, A computational study of direct simulation of high speed mixing layers without and with chemical heat release, Proceedings of the 23rd symposium (international) on Combustion, pp 707-713, 1990.

4.8. The 25th Int. Symp. Comb. at Irvine, California, USA, 1994

We had submitted a paper to the 1992 symposium to be held in Australia. This paper was related to SD's work on wood char gasification in carbon dioxide - nitrogen mixtures. It was rejected because all the three reviewers gave low ratings. This appeared a bit surprising, more particularly because the ratings were low from all the three reviewers. On a scrutiny of the reviewers' comments, it appeared as though the reviewers may have been at best graduate students because the reviews contained questions on the meaning of symbols that were already available in the text, but not as symbols and they sought clarifications instead of authoritative comments. I wrote a strong enough communication indicating the poor quality of the reviews to Prof. C. K. Law who was the program chair on this subject from whom I received the usual stonewalling kind of response. I could not get out of my mind that some petty jealousy was responsible for such decisions. These received indirect confirmation at the next conference in the dinner table conversations with our friends among Indian-American academics. Anyway, the paper appeared in Chemical Engineering Science in early 1994. In the real world of science publishing, this experience was unusual for us, but not uncommon.

For the 1994 symposium, we submitted Dasappa's work on wood char gasification with oxygen and nitrogen mixtures on single particles of char and was accepted for presentation. In my view, the quality of the paper that we had submitted to 1992 symposium was higher and yet had not been accepted. All the three of us, SD, PJP and myself went to Irvine. The high point of the visit was a dinner meeting with Prof. Kanury Murthy and long discussion on science and technology.

After this conference, we travelled to Sweden to visit the Royal Institute of Technology at Stockholm to firm up the aspects of a collaborative project to perform tar analysis from IISc gasifiers. Two of our collaborators from here were Mr. Truls Liliedahl and Dr. Sjostrom. Mr. Truls Liliedahl was an interesting happy go lucky person and did not appear to be deeply into academics. His being casual became clear when he discovered that he did not have the visa to come to visit us after he started for the journey!

We were shown their laboratories and what they specialise in - analysis of complex liquid phase compounds. At IISc we had identified Dr. Jayamurthy to work on this project and we had to settle the details of the actions required as a part of the collaborative project.

With the help of Sjostrom, we also visited a gasification company called TPS Terminska Processor AB (short name: TPS) and its technical lead in Dr. Eric Rensfelt, a bulky man but very mobile and dynamic and we had valuable visit to their laboratories with open discussions. We also could communicate with him how good our system was and why we thought so and felt that we were talking to somebody who could understand what we were saying. The situation in Europe then and even later was such that they would be polite in listening, but disbelieve without really understanding the science. At this stage it may be appropriate to state that the only person who could understand the science and technology was Dr. Thomas Reed from the USA and he surely thought that what we had done or got was outstanding. He visited us twice in a few years and spent time to discuss the processes inside the gasifier.

S Dasappa, H V Sridhar, P J Paul, H S Mukunda and U Shrinivasa, "On the combustion of wood-char spheres in O2/ N2 mixtures - Experiments and Analysis", proceedings of the 25th International Symposium on Combustion, Irvine, California, USA, 1994.

4.9. The 26th Int. Symp. Comb. at Naples, Italy, 1996

Nikhil Patel had joined as a research student initially (somewhat wildly) interested in subsonic ramjets. It took some time to persuade the enthusiastic Nikhil to take a problem other than this (that could be considered new) since subsonic ramjets simply will not produce thrust. It turned out that at that time, zero-effluent discharge concepts in distillery effluents were demanded by one distillery. The effluents had around 10% dissolved solids. Our idea was to evaporate the effluent, extract the dry solids (at 10% moisture), burn it up, generate the heat that could be used as a heat source in a multi-effect evaporator for the waste effluents. The energy balance was not entirely clear, but any negative balance could be handled with additional renewable energy source like biomass combustion. One part of the research effort of Nikhil would be to study the dried effluent sludge in spherical ball combustion mode due to the history of successful studies on liquid and polymer droplets as well as wood spheres. The sludge material would fall in between and it would be interesting to study the particle combustion behaviour. This was the subject of his work and the paper was accepted at the Naples symposium and it was presented. His work for Ph. D went ahead with also trying to successfully do air gasification of the liquids themselves as a spray at highly loaded fractions (up to 75% solids). This symposium was attended by Nikhil, PJP and myself. Subsequent to the symposium, PJP and myself went to Rome, saw around and left for Sweden to pick up threads on our collaborative project with Royal Institute of Technology. By that time one of the staff members there had some ideas on gasification and was conducting experiments and wished to have some discussions as well. This journey was performed on a train which was carried by a ferry from Putt-garden in Germany to Copenhagen and then on to Sweden, a very interesting journey, partly through the night.

Nikhil. M. Patel, P. J. Paul, and H. S. Mukunda, Droplet combustion studies on dried concentrated distillery effluents, Proc. 26th International Symposium on Combustion, The Combustion Institute 1996.

4.10. The 27th Int. Symp. Comb. at Boulder, Colarado, USA, 1998

The research on wood char gasification was extended to include packed bed of char, something that occurs in actual gasifiers with charcoal as the fuel. The work included single char particle conversion with carbon dioxide and water vapour at high temperatures and the gasification process in a packed bed, all these being pursued experimentally and also modelled to get predictions of the propagation rate. We used this occasion to touch base with Dr. Tom Reed who had visited us at Bangalore. He was staying in a place between Colorado and Golden, the location of NREL. While we actually wanted to visit NREL, we did not get the permission because of sanctions imposed on India due to nuclear explosion (at Pokhran) at that time. We were invited by Dr. Reed to his home and we had dinner. We invited both Dr and Mrs Reed for a dinner at a restaurant in Colorado a few days later. We had an technically relevant enjoyable time both at the conference and in discussions with Tom Reed where he engaged us in depth on the nature of our fundamental work on biomass and char. Of course, men and other matters also were discussed.

S. Dasappa, P.J. Paul, H.S. Mukunda and U. Shrinivasa, Wood-char spheres gasification: Experiments and analysis on single particles and packed beds, proceedings of the 27th Symposium (International) on Combustion, pp. 1335-1342, The Combustion Institute, Pennsylvania, 1998.

4.11 The 29th Int. Symp. Comb. at Sapporo, Hokkaido, Japan, 2002

By this time, PJP and myself having received acceptance for ten papers over a period of two decades after having attended eight symposia had become very were familiar face to all the old timers and we were called Indian group, the only group seen at the international symposia consistently.

The Sapporo symposium had two papers - one by P. A. Ramakrishna and another by Sudarshan Kumar. Sudrarshan's paper received an award as well. Ramakrishna's work was related to a rigorous computational study of two-dimensional sandwich and Sudarshan on fundamental investigation of flameless combustion. Ramakrishna, Sudarshan, PJP, and myself attended this symposium. The papers were received well and Sudarshan got his award in the conference dinner.

Subsequent to the symposium, PJP and myself went to Hiroshima where the head office of Satake Corporation was located. We had transferred the biomass gasification technology to them some years back and while things were moving, there was indication that management push was indeed necessary to ensure firm commitment to progress the technology. Towards this, we were met with by Mr. Haruo Tarui, the technical and commercial interface with IISc at the airport and driven to the offices of the corporation. We were received with the usual bending forward welcome gestures typical of formal Japanese custom. We reciprocated and went in for the meeting. We made the usual noises and indicated that considerably enhanced support in terms of increasing the number of projects that they should undertake may be needed to obtain commercial benefits from the technology transfer. The meeting was over in about 45 minutes and we left the office with again traditional goodbye. Three of us drove to a Japanese restaurant and ate dinner since we had little food throughout the day. Actually, we were famished. After the dinner, we were taken to the hotel where we checked in and stayed overnight. The following day, we left by train to Tokyo to take the return flight back to India.

P. A. Ramakrishna, P. J. Paul and H. S. Mukunda: Sandwich Propellant Combustion Modelling and Experimental Comparison, Proceedings of the Combustion Institute, Vol 29, pp 2963–2974, 2002

Sudarshan Kumar, P. J. Paul and H. S. Mukunda: Studies in High Intensity Low Emission Burners. Proceedings of the Combustion Institute, Vol 29, pp 1131–1138, 2002

4.12. Asian Congress on Fluid Mechanics, Beijing, 1983

In 1983, there was an announcement for Asian congress on fluid mechanics being held in Beijing, China. The papers were to be selected from amongst those submitted to the committee in India and those whose papers were selected would be able to participate in the conference paid by the Indian committee supported by the Government of India. This was one way of flexing the muscles of the Indian scientific groups through Governmental support. There was a piece of research done by one of the master's students with BNR and myself as the supervisors. The subject was the flow behaviour in the dome of Viking engine that was to be used in PSLV second stage. The paper was accepted for presentation and publication in the proceedings. BNR at that time was away in Japan and he had to specially make efforts to visit China. In my case, the process would get organized as a group and would not entail any effort on my side other than providing a valid passport. After a communication, it was decided that I would present the paper. The travel was through Bangkok with an overnight stay. It was fun going on this trip that was very much more relaxed than the international combustion conference. I had also occasion to meet with researchers from other Asian countries. I remember that Prof. Batchelor from Oxford attended the conference. He was very sharp on one of the presentations by Prof. Rudriah of Central college indicating that the physics he is modelling was unsound. Some presentations from Japan were outstanding for the fineness of experimental detail. Nothing else of significance resides in my memory including my own presentation which I expect was average considering the nature of audience.

B. N. Raghunandan, A. Vidyarthi, H.S. Mukunda, P.J. Paul, Fluid Flow Studies on Radial Injectors in Liquid Rocket Engines, Proceedings of the Second Asian Congress on Fluid Mechanics, Beijing, China, October 2-30, 1983

4.13 Recording lectures at Sapienza university of Rome, 1994

I received an e-mail from a Professor in the University of Rome (Sapienza means wisdom) asking if I could come to the university and deliver lectures that would be recorded for the UN university for use in its institutions across the World (there are 12 such institutes across the globe). After back-and-forth communication, it was agreed that I would visit Rome in December 1994 for a period of seven days with lectures of about one and half hour duration recorded twice every day for five days. I spent a delightful seven days in a small hotel not far from the main station, Roma Termini and also about 1.5 km from the university. The travel to the university as well as the Vatican City area was all done by walk along different routes to cover the area! I got tired of eating pizzas every day of the week even after sprinkling with a spices-filled powder (called “chatni-pudi”) I had taken from home to provide some different taste and was happy to return home.

4.14. Specialist workshop in Stuttgart. Germany, 1996

This was by an invitation in 1996. Our work on gasification had reached wider audiences in Europe because of the involvement with Switzerland, Mr. Buehler and Dr. Sharan and other scientists from ETH, Zurich. We made two presentations at this workshop. One was the possibility of using shaped and sized fuels of biomass from agro-residues and firewood and another paper was on measurements of tar from the gasification systems - both of open top down-draft kind and of cyclone gasifiers. The measurements were carried out by Dr. M. Jayamurthy in a joint project with the Royal Institute of Technology, Sweden. Mr. Truls Liliedahl was the principal research engineer interacting with us. This meeting had many stalwarts on gasification from Europe and there was intense discussion on many topics. There were presentations on liquid pyrolytic fuels from several scientists from UK and other countries. There was one study in which the pyrolytic fuel was expected to tested in large diesel engines. It was clear that there were serious ignition problems and this approach would soon get disbanded. The investigators, however, went on asserting the virtues largely because they were funded for the study. Years later, the technology has not seen the light of the day. We benefited a whole lot because the science and technology of gasification that was developed at IISc got a very good exposure.

Jayamurthy, S. Dasappa, P. J, Paul, G. Sridhar, H. V. Sridhar, H. S. Mukunda, N. K. S. Rajan, (all from CGPL, IISc), C Barge, T Liliedahl, K Sjostrom (all from the chem engineering and technology department, Royal Institute of Technology, Stockholm), Tar characterization in new generation agro-residue gasifiers - cyclone and open top twin air entry systems, published in Biomass Gasification and Pyrolysis: State of the Art and Future prospects, Eds: Kaltschmitt K and Bridgwater AV, CPL Press, UK, 1997

4.15. Lectures in Brazil

4.15.1. The long journey to University of Itajuba and Paraiba

I received an invitation from Prof. Pio Lobo of Escola Federal Engenharia Instituto (Federal school of engineering institute) of Itajuba, Brazil, for a month long program in Brazil. During this period, I was supposed to present a course, visit several places and also visit the university of Paraiba. I left Bangalore by Air India flight on 03, November 2000 at 0200 hours. The check-in staff cribbed about accepting the three-piece baggage as carry-on baggage. They gave a lecture to the old professor and let him go. Only afterwards it is that I discovered that not-so-old professors were also carrying a fair amount of carry-on baggage. The journey to Mumbai was uneventful. They announced the flight as AI 447. I was surprised. The flight became AI 101 from Mumbai. I had to get down, wait for another hour and a half before boarding was announced. The flight scheduled to leave at 0630 hours, left at 0715 hours and reached London at 1130 hours local time after traveling 7200 kms in 9 hours. The time gained was five and a half hours. At the transit area, SAS airline personnel checked me into the RG 757 flight and I waited for ten hours at the airport. I simply slept on the vacant chairs for several hours, ate up apples that I had taken, drank some coffee and moved around totally disinterested in the dazzling shops of all kinds. The flight left at around 1150 hours local time and arrived at Sao Paulo at 0730 hours (local, Indian time being 1500 hours on Saturday, the 04 – 11 – 2000) ten minutes ahead of schedule after flying about 10500 km. There was routine check at the immigration and was waived through the customs and walked out of the airport to see Prof. Lobo waiting for me. I was relieved to see him and we left the airport by a car belonging to the university.

4.15.2. Course at Itajuba

We arrived at Itajuba after two and a half hours drive on highways comparable to those in USA, (for instance) and later in smaller roads, for an hour and a half. Some places that I saw were very much like villages in India. We arrived at Itajuba by 1215 pm on 4th Nov 2000. I did not seem tired at all. Relaxed for some time and went for lunch with Prof. Pio Lobo. Five minutes of walk and we entered a very interesting hotel – food to be paid by the kilogram. I was shown rice, a vegetarian gravy, and salad bar in which most of it is vegetarian. Found very good water melons, papaya, pineapple, brinjal (this is also the word in Portuguese) pieces of which also formed my food. I ate half-a-kilogram of food! From this day onwards, I watched that I was eating 0.45 to 0.47 kg of food every day afternoon. The weather in Itajuba (900 m altitude) is much like in Bangalore. The hotel I was staying was called Centenario and just around that was a small beautiful square with trees and sitting places around which there are eating shops.

In Itajuba which must be 4 km by 4 km size, about 80,000 inhabitants lived in average size houses, 500 to 700 m^2 largely in packed houses. Most houses had a high compound wall mostly as a matter of protection. Most flowers found in India were also seen here. Sampige (Champaka in English) and other flowers were seen around. They were totally insensitive to flowers except as a gift, greeting, in which case one had to buy a bouquet. I could see parthenium (congress grass) at several places. Fortunately, they were not widespread. The first two days – 6th and 7th November 2000 were spent in lectures using most of the material that I had. There were ten students. Most of the local students did not know English at all. Even the TV did not have anything in English. Even the US movies that were dubbed did not have English sub-titles. I told many of them that this was a serious defect and unless the large younger population learnt English, it would be difficult for them to compete in the new economic world dominated by USA, UK, and Europe all of whose activities which are international are based on English. I was supposed to give more lectures, but there was nothing new on the subject that I could keep talking indefinitely. In one blank session, they asked about economics of biomass power generation and I worked with them with the numbers that they provided. It showed that the costs of fuels were about the same as in India and the economics similar. But there was an exception. The domestic rates for electricity were double that of industrial electricity. Two days were spent in building a small gasifier that should work! The workshop staff cooperated, an old blower was searched and brought out from junk yard, and the entire system was fixed by Friday morning. I had to look for charcoal in the junk yard and brought out a few kg for use in the gasifier. Everybody clapped (!) when the gas burnt in a small stove meant for smithy. The show was over by 1130 am. I really wondered if the gadget would work at all afterwards. I understood from Prof Joule, who had helped put together the system (he and three others had literally carried the heavy fire box with blower mounted on it for a hundred meters to bring it from the backyard (another name for junk yard) the previous day evening using two long wooden poles!). Prof Joule and two of the mechanics managed to restart the gasifier and run it in the afternoon, it seems – very gratifying!

4.15.3. Technology Center of Copersucer, Perisicaba

The visit was intended to discuss the ideas of gasification with sugar industry. Manuel Regis Lima Verde Leal – Manager Industrial Technology, Jose Antonia Giardini – Chief, Process technology section and two others participated, including the general manager who was the first student of Prof. Pio Lobo.

The manager, Leal was very competent and knew what he was talking. He was the partner in the BIG-GT project funded by World Bank/UNDP with TPS as the technology institution. They were a private company with money coming from sugar cooperatives with 1% gross profit being a part of their budget. However, this money could not all be spent on technology; they were partly used to maintain the senators and congressman towards subsidies (!). They had a ISO 9002 certified laboratory

for checking the quality of sugar and ethanol. They had a modern plant science laboratory. They specifically did DNA typing of new varieties, test grew them in their fields to check pest resistance, growth rate on a 5-year cycle basis, etc, etc. The harvesting schemes were also considered important. They developed mechanical harvesters which could harvest 8 to 10 tonnes per day compared to 5 to 7 tonnes per day from manual harvesting. This also allowed one to use the tops and leaves in the boiler. It appeared to me that from the point of view of co-generation, India had progressed much more than Brazil.

In respect of thermochemical conversion, he indicated that from his perception, he preferred the atmospheric gasification route since it was reliable even though there was loss of efficiency. The Vernamo "high pressure gasification – GT engine" plant seemed to have been shut own with the consideration that the plant would not be useful for anything other than wood chips and their experiences with candle filter were not encouraging. During the conversation he brought up the experience in Hawaii and stated that feeding bagasse in the high-pressure system gave him scare by looking at briquetted biomass in the feed system at Hawaii plant. This was also a bit of news to me.

We adjourned for lunch and after lunch we were shown around and we met again. This time he wanted me to speak about our work. I began by stating that for somebody who knows what is important and where he was going, I did not know if he would be interested in kWs at all. He genuinely showed interest and I explained to him with the material on my laptop. He appeared very interested, deeply impressed and indicated that Brazil has considerable need for the 100 kWe class technology in various parts where grid could not reach, etc. He suggested that we should talk to Alfonso, Horta, and a few others in Brasilia to which Prof. Pio stated that it was the part of the plan to see all of them. I also described the high-pressure gasifier work as well as the plans for drying bagasse and briquetting – gave him the numbers on energy for briquetting (80 units per tonnes) and the sizes at which these were intended to be made, etc. He made extensive notes at this time.

All this was at the end of 2000. Now it is 2021! Nothing has progressed on the biomass technology related aspects.

4.15.4. Prof. Electo de Silva, EFEI

Prof. Electo had created a group called NEST and Prof. Pio belonged to that group earlier. They seemed to work independently since intellectual independence and freedom of work are the points of weakness in NEST. Prof. Electo seemed to have moved around the world quite a bit, made connections, written books – about six and was known better, something he always attempted to establish in the conversation. He had a large project on developing an ambient pressure fluid bed gasifier, cool and clean the gas before compressing the gas to run a 45 kWe micro-turbine of Elliot make. A student of Jans Andries of Holland spent six months, designed the gasifier, got his master's degree and had left. The system was under construction in a company close to Compinos. He was acting secretive about this with Prof. Pio. On 15th evening when I was walking around the town taking pictures of the high sloping roads, congress grass plants, plants with flowers similar to ones at home, Prof. Electo was driving towards his office, stopped and asked me if I could go with him for a cup of tea. I said, yes and went with him. He spoke of his life – he was in Russia for nine years from where he got his Ph. D. He worked both in Odessa and St. Petersburg. He married there, had a son and divorced while leaving Russia. He stated he had very nostalgic memories of Russia and so on.

He had a collaborative project with Jans Andres and it is in this project that a student of Jans worked here for his master's degree and designed the gasifier. He said that one year ago when he visited Jans laboratory a combustor was being tested with the gas from his high-pressure gasifier. When I indicated that he had written to me indicating that he is running a gas turbine engine, he showed ignorance; just stated that something must have happened in the last year and left it at that. On another side, Jans wanted to check with Prof. Pio as to what I was up to at EFEI. He might be feeling that his possible empire was being invaded, I didn't know. Prof. Electo mentioned that he once got to speak to Eden Prabhu in a conference, found him to be secretive (look who was saying!). I agreed with him and looked like giving my advice that he should keep away from him. Apparently, Eden was anxious in knowing what Electo was doing with micro gas turbines. I thought within myself, we should also be careful. He then showed me the thesis of the student of Jans written in English. I saw through that. He had used various correlations and put up the design. Nobody seems to have looked at the engine interface yet. This might create a problem. The numbers indicated in the thesis seemed to take the tar level as 1 to 10%! The temperature range chosen was 800 to 1000 K. When I asked why temperatures of 1300 K were not considered, he indicated that ash fusion problems were his worry. It is this temperature range that makes him get 1 to 10% tar, way above what one expects in a good gasification system! I asked whether any experiments had been made at all. He indicated in the negative. I do not know how they would deliver any performance from the system. He appeared to be a collector of literature. He had our full report of tests on 75 kg/hr gasifier tests done with Swiss support.

He stated that Nusbaumer was his good friend. There seemed to be some soft corner for him. Perhaps he might have given this report.

4.15.5. Prof. Kamal Ismail, University of Campinos, Campinas

On the way to Perisicaba, the place of Copersucar, we spent an hour talking to Prof. Kamal, a former colleague and friend of Prof. Pio Lobo. He indicated that he was a consultant from Uni. Campinas to establish the academic profile of an university in north east. He stated that there were large communities in the area without even the minimum facilities of electric supply. I gave the usual presentation. He found immediate possibilities of use for the technology in those areas. He asked me if I could come to that university and give a similar course and how soon. I indicated that it was not necessary for me alone to come; there were others who knew the subject from our laboratory and they could give the course as well and outlined the plan.

Prof. Pio explained the whole concept. Prof. Kamal stated that he might be able to get money faster than Prof. Pio could do. I stated that unless there was at least one center for doing tests, demonstration, training, and supply critical parts, it would not be appropriate to introduce the technology in this country. Inevitably, there would be problems of operation, maintenance and new questions would be brought up and it was essential to have a few centers for providing technical back up and at least one center. He generally agreed with the philosophy and stated that he would work with Prof. Pio Lobo and us in times to come. However, nothing happened subsequently. I know this since I was back in Rio de Geneiro an year later and check with Prof. Pio Lobo showed that Prof. Kamal had not reached out to him.

4.15.6. Wood factory 30 km from Itajuba

In the afternoon of 14th Nov 2000, Prof. Joule took us to a wood factory about 30 km from Itajuba. It was mildly raining and temperature was about 20°C. The drive through the mountains was exhilarating. There were several beautiful towns/villages along way tucked into the valleys of the mountains. It must have been an expensive affair to take electricity to these towns.

The wood factory processed Canadian Pine grown in the mountains around. Incidentally all the mountains were owned by private individuals like land being owned. Canadians had taken about 300 Ha of land, leased it to owners of this factory, and provided the seedlings to grow the plantations. The reason they did this was due to the fact that the same seedlings took 60 years to grow into an acceptable mature tree in Canada but take 28 years to grow to the same maturity in Brazil. The claim was the soil and climate here were more suitable for the appropriate growth. This appeared also the reason for very good Eucalyptus output from plantations in Brazil – 15 to 25 tonnes (dry) per hectare per year in a five-year cycle. The factory was very old – thirty years. It had a boiler built in 1938. This was similar to the approach in India. It was otherwise managed efficiently. The pine trees exuded a very nice smelling resin typical of these trees. The whole trunk was sized into pieces, dried and cured at 60°C for 24 hours using indirect steam fired system and machined to several forms and shipped away to Canada. Sawdust was simply washed away by a stream of water that flowed out of the factory, the water filtered in a bed, and the sawdust remained as a mound with water going away into another mountainous stream. There were cubical pieces 100 to 150 mm size at 50 to 60% moisture converted to charcoal in an Igloo like civil structure, a part of which was put together with bricks and mud every batch (much like pit method, but over ground, that is all). Long pieces of wet wood unsuitable as furniture material were used to fire the boiler. The exhaust from the chimney looked very clean. This must have been due to firing 50% wet wood and possible excess air. The aim of the visit was (a) to find out if wood chips could be obtained from them and/or (b) improve the operations so that heat or electricity generation was possible. Also, Prof Joule had an idea – if we condense the vapours from drying chambers – both with the actual product drying as well as waste wood – we could obtain the resin and it was possible it would have commercial value in the perfume industry. This completed the visits. Wednesday was a local holiday.

4.15.7 University of Paraiba, Joan Pessoa

On the afternoon of 16th Nov. 2000, I left Itajuba to go to Sao Paulo to get the flight to Joan Pessoa in the north east of the country on a visit to University of Paraiba - Prof. Emerson Freitas Jaguaribe of the department of Mechanical Engineering.

The ticket arrangement for the visit was interesting. The ticket was bought at J. Pessoa and a code number was provided. I was supposed to go to Sao Paulo airport and give this information to ticket issue counter. They would then issue the ticket. The driver of the vehicle knew all the ropes and helped me get the ticket. He was supposed to have arrived at Hotel Centenario at 1430 hours at Ita Juba, but came only at 1505 hours. This caused some concern, telephone calls, etc. But the driver promised that I would be delivered at Sao Paulo before 1800 hours for a flight leaving at 1908 hours. We left and he drove very well through a different route (apparently, there are four to five routes from Itajuba to Sao Paulo.). He drove sometimes at 140 km per hour, but very carefully. We spoke a few words in between haltingly. We reached the airport without stopping anywhere for agua (water) or coffe (as they call it) and arrived at the airport at 1750 hours and went to the spot for getting the ticket. It was very smooth. The lady asked for my passport and handed in the boarding pass. The flight was from Sao Paulo to Salvador. At this place there would be a change of plane to go to Joao Pessoa. As soon as we got down from the plane, we were physically herded on the tarmac to the next plane.

The next segment of the flight also seemingly came to an end and I got down, went to the airport to look for my baggage – did not get it and went in search of the person to get my baggage. He stated that the baggage was to go to J. Pessoa. I said I also want to go to Joan Pessoa (!). He said that this is Aracaju (Caju in Portuguese and Hindi mean the same). I was shocked. The person did not seem concerned at all. He just said – let us go to the aircraft. I went back into the aircraft and asked the attendant there as to how come, the boarding pass does not show Aracaju as a possible intermediate point. They simply said sorry and moved away. Anyway, I landed at Joan Pessoa at 10.30pm (local), 12.30 am (17th Nov. 2000) according to Itajuba time (0730 am, 17th Nov. 2000 according to Indian time), got the baggage intact and was picked up by Prof. Emerson and driven to a hotel near the beach. I slept about five hours and found that the sun was bright even at 5.30 am (local). Got ready, finished the breakfast of watermelon pieces, pineapple pieces and bread pieces and got ready to go with him to the university by 7.50 am.

We went to his laboratory at the university, and he showed around the equipment meant for determining the properties of activated charcoal. They had a PSA (Pressure Swing Adsorption system that we also wanted to get) apparatus for getting 100% pure nitrogen. This is used for BET apparatus. They have made measurements of Iodine number and BET surface area. The measurements also give the data of the volume adsorbed as a function of pore size. The curves are plotted on a semi-log paper. For many cases they get the results like the volume of 0.12 to 0.14 cc/g at 20 A going down to 0.01 cc/g at 1000 A. If he did it with the outer part of the coconut shell, he got a curve which is like a delta function at 800 to 900 A. He believed that this was very good for removing chlorine from water. His point was that manufacturers of drinking water, Coca cola, Pepsi, etc all had to first chlorinate the water to remove bacteria and then had to reduce the chlorine below the acceptable limits for human consumption and this could be accomplished using this kind of activated carbon. I asked him if he knew the correlations for Iodine number and Methylene Blue number. He indicated that he did not have data, but he had many useful comments to make. He indicated that they had an intense Japanese collaboration for the last six years with the University of Yokahama with visits both ways and equipment from Japan. Japanese use Benzene as the adsorbent, but did not talk about it because, Benzene was considered carcinogenic and therefore should not be used in industrial laboratories, etc. He himself did not have experience in using Benzene, but indicated that Iodine was a good reagent. I just indicated that various reagents had use in different applications since the molecular size of the substance to be adsorbed would matter and perhaps, Iodine was representative of many materials that were to be adsorbed and that was how it had become the standard. He had no special comment to make on this.

After this visit, I flew back to Sao Paulo and took the return flight to Mumbai, India.

4.16. Conference in Rio de Geneiro, Brazil, 2001

In early 2001, I received a letter from Dr. J. Goldenberg (a Brazilian scientist-administrator who had worked with Prof. A. K. N. Reddy) inviting me to give a talk at the specialist conference to examine the status of small-scale biomass gasification 28 – 30 June 2001 at Rio-de-Geneiro. He had also invited European experts, one of whom was Hubert Stassen. He also had a presentation to make. The plan of Dr. Goldenberg was to make us adversaries, initiate a vigorous discussion on the techno-economics and get to the bottom line on electricity generation from biomass. There was indeed very vigorous discussion, sometimes in English and sometimes in Portuguese. I think Goldenberg secretly favoured the option I had suggested, but wanted me to defend it publicly in the presence of Stassen who had the reputation of having seen many gasification systems in Asia and somewhat of mixed view on the techno-economics and operational issues. The tragedy was that the science needed to evaluate the new technology that I was arguing for was not something he had assimilated. We discussed for a while and it was inferred that the audience could draw its conclusions. I returned from this conference which was also attended by Prof. Pio Lobo in whose university at Itajuba I had spent a month in November 2000. We spent talking and walking around in the famous Copacabana beach during the evenings on the two days of the three-day workshop.

It is perhaps appropriate to state that there was only one other person apart from CGPL group who had understood the IISc technology. It was Dr. Tom Reed. He had made visits twice to CGPL. The first time, he wanted to understand the behaviour of the open top re-burn system, particularly the re-burn part as it lent the system a degree of robustness missing in either the closed top or open top non-re-burn system that he had designed. He in fact visited us a second time in cooperation with another manufacturer to examine if he could get the know-how without having to pay any technology transfer fees or related arrangements. This had put me into serious problem at IISc and I narrowly escaped being crushed in between!

In any case, the meeting went off well and IISc technology appeared to remain untarnished and golden!

https://documents1.worldbank.org/curated/en/583671468769505568/pdf/multi-page.pdf

4.17. Workshop in Yogyakarta, Indonesia, 2003

I received a mail from ARECOP organization, specifically from Mr. Erwan Kow (also copied to Christiana Aristanti, Aryanto Sudgarwo) that they had a workshop on improved cook stoves and they wanted me to attend the meeting on improved cook-stoves and make a presentation on advancements made by us in this regard. They were funded for promoting the improved cook stoves activity by an US organization (perhaps, USAID). They had found that apart from being an academic and a researcher, I had been the chairman of Biomass users network headquartered in New Jersey. I accepted the invitation and spent five days in Yogyakarta (also called Jog-Jakarta) during 30 September to 01 October 2003. I presented the talk and got involved in discussions on way forward. I brought out the fact that unless we used forced convection by using fans, we cannot reduce the emissions and we should not be fixated on efficiency. Efficiency improvements will take place automatically when good fuel - at least sun-dried sized fuel is supplied with a quality not unlike LPG and kerosene along with forced supply of air. Whether the poorer sections of the society can afford to buy these products that may have a higher first cost will be determined by the subsidy structure that the Governments are interested in creating for improving the affordability. For a slightly larger scale cooking, the perceived costs will get in affordable class.

4.18. Workshop in Chiang Mai, Thailand, 2007

This appeared like as follow-on workshop aided by FAO and took place between 21 - 26 January 2007. During this time, my wife joined me as she did not have any responsibilities at home and the visa was on arrival as a tourist. We were well taken care and stayed in Chiang Mai for three days and two more days in Bangkok (largely as tourists). The conference was attended by a much larger group of people who were handling industries using expensive energy sources and intending to switch to biomass-based energy from other east Asian nations - Cambodia, Vietnam and Laos. There were presentations of their perceptions of the transformation needed. There was discussion of options and how to go about dealing with them. Economy in operations was the main driving force for the choice of technologies. Occasionally, down-draft gasification technologies were sought. There was a conflict with clean technologies being more expensive and the difficulty in adopting them. This was subjected to some discussion and I pointed out that some new technologies would be able to pay for the investment in less than two years and if the investment costs are provided at subsidised interest rates.

4.20. Workshop in Kunming, China, 2001, 2007

There were two visits to the same city, Kunming. The first one in 2001 and the second one in 2007, both organized by FAO. During the first visit between 8 to 13 Sep 2001, I was expected to take part as a combustion scientist to understand the biomass-based combustion systems that were in production and adoption there and calibrate them for possible adoption in other developing nations. Just in the middle of the workshop the event related to 9/11/2001 took place in the USA and the videos showed them in the night.

During this period, we were shown around to see the factories where they were building stoves and combustion systems. These stoves were heavy and perhaps not the type for domestic cooking. There were no designers or academics participating in the discussions. I passed on my views and impressions to fellow colleagues who had come from various countries. Any explanation to the Chinese manufacturers were responded to by showing that the systems were performing. I could not engage with them in a detailed discussion asking for the specifications and performance details.

The second workshop held between 21 and 28 July 2007 in Kunming in a university area was aimed at providing training on the science of combustion and stove Glassmanperformance. I had taken with me Prof. Bhaskar Dixit who had completed his Ph. D. on a scientific study of pulverised fuel combustion systems classically in existence for over a century. The participants were NGO's from various south east Asian and SAARC countries. There were a series of lectures for three hours in the morning and exercises in the afternoon. We had requested them to specify their projects first, work with them to determine the specifications of a combustion system and ask them to design the system. Since most of the participants were not quite "design" enabled, we had to sit with them and provide step-by-step inputs for the design. This proceeded over the week with occasional visits to factories. One factory we visited was identical to the one I had visited earlier. Two of the participants were from the USA, Mr. Dean Still and Dr. Paul Anderson. Mr. Dean Still, a careful elegant speaker knowing his limitations and yet acted as an expert in the meetings at Kunming. He would provide advice on his own on heat transfer and related aspects, would enthusiastically declare that some observed product was good, excellent or some adjective even though he perhaps did not believe in them. He was a successful head of the APREVECHO organization in Oregon and was invited to write about stoves by the International Energy Agency. Dr. Paul Anderson was a faculty member in Geology, got interested in stoves, participated in the biomass cooking design workshops, interacted with Dr. Tom Reed and undertook the propagation of this stove enthusiastically and passionately. Occasionally his science would flounder as it happened in his attempt to show how his new design was very good, but it did not actually work at all. I think the science that they had really understood or were propagating over a time seemed far removed from what Dr. Tom Reed, the scientist who had initiated in the USA. They spent time at the workshop with somewhat of a superior presence and on occasion had to be contained to ensure improper transfer of the crucial aspects of the science of combustion during the discussions. During all this period, much to the disappointment of the organizers, FAO and ARECOP, almost nobody from China participated in the workshop. Much discussion of this too place on the side-lines.

4.21. Myanmar - as Expert Advisor, 2001

In December 2001, I received a call from one of the Joint secretaries of the ministry of external affairs (MEA) of GoI stating that they had a request from the Government of Myanmar for an expert to visit them in Biomass gasification and would I agree to go on behalf of Government of India. On further enquiry, they indicated that they had received the information through their embassy that I was the expert whose visit was being sought. I agreed to the request. They sent me the necessary documentation to get the visa and I went to Myanmar on 7th January 2002. I was received by a dhoti-clad somewhat nondescript person and taken to a hotel. Later that afternoon, I was taken to see the minister of education who was a Ph.D from the imperial college, London. The minister also seemed to be in dhoti-clad attire. I was a bit surprised. but did not show it. The conversation was smooth and technically reasonable. He stated that they had technologies for converting rice husk to producer gas and they wanted electricity to be generated using a reciprocating engine, perhaps a gas engine and if not, at least a diesel engine. I agreed to look at the technology that they had. I must also say that they were very courteous and pleasant even though it was a military regime and, on the average, I did not see fear anywhere during this period. After lunch, I was driven to an industrial area where the gasifier was located. It appeared that rice husk was to be introduced without further pre-processing. Though I knew that this effort would lead nowhere and I could have said as much even on a telephone call, I played along because courtesy demanded that I do so.

Between the meetings, I was taken out to some shops for me to buy some souvenirs for myself and I could not pay on my own. I forced the person who took me around to find a way by which I could convert dollars to the local currency and buy it from that. He relented finally and told me that I could give dollars directly in some shops and buy. I did this. I also visited the prominent Buddhist temples around.

There was a dinner with all people involved and one military chief who was a minister senior to the minister who was taking care of the discussions on the technology. We got to talking about generalities and I was a patient listener.

On the final day, I opened up and indicated to them the limitations of the approach they had chosen, I showed how rice husk briquettes made from Japanese machines could generate high quality gas in fixed bed systems for long durations and explained the physics and high temperature chemistry related to ash fusion that would prove a nemesis for unprocessed rice hush based gasification systems and said all the operations of Chinese in using raw rice husk was blown out of proportion without adequate performance analysis and the associated economics of operation. I suggested that I would always be available for any further discussion, and some scientists working could visit us at the laboratory and we at our laboratory would happily work with them in an open way.

Beyond this period, there was no further contact and I guess their wishful expectations remained unfulfilled.

4.22. International Science Panel for Renewable Energy (ISPRE), 2007 - 2009

The Indian National Academy of Engineering wrote to me in late 2006 that they wanted to nominate me as a member of the International panel on renewable energy and wanted to receive my concurrence. I responded in the positive and there began a three year - three meeting arrangement to generate a report for the international community on renewable energy. The meeting was chaired by Dr. Jocham Luther who was the director of the Fraunhofer Institute for Solar Energy Systems ISE, Germany. The meetings in Paris were held at the office of International Science Council in the period 17 - 20 January 2007 and 02 - 05 February 2008. There were seven other attendees. I did not know any of them and I guess they did not know about me. I was looking at biomass-based energy which appeared novel to the members excepting the one from Africa. I discovered that the North African communities were influenced by France to a significant extent. In many countries people can actually speak French language. I made a presentation of my perception of the World scenario in biomass-based energies and indicated that slowly but surely, solar energy will begin to take root in delivering electricity at rates that may become subsidized by the Governments and thus enable large scale manufacture and adoption. And so, it would become imperative to pay greater attention to delivering clean cooking heat as well as high grade energy to small industries by adopting advanced biomass combustion technologies.

(https://council.science/wp-content/uploads/2017/05/ispre_biomass.pdf)

4.23. UN university - Bonn, Germany, 2009

I and my wife were with our son in Gottingen, Germany for a brief while when he was a post-doctoral fellow at the Max Planck Institute for Solar System Research, Gottingen. Based on an invitation, we went to the UN university at Bonn on 17 July 2009 for me to present a talk and hold discussions on renewable energy. I presented the research, technology development and field outreach aspects of biomass energy research at CGPL.

There were other presentations on the dialogue for sustainability, STEP - solving the E-waste Problem, the energy component of the project on sustainable land management in the high Pamir and Pamir-Alai mountains, and the human dimensions of global environmental change.

The conclusion I came to after the interaction that lasted through the lunch was that though the team was enthusiastic, the UN system was generally a slow one when it came to implementation unless there was a catastrophe.

4.24. US Navy invitation - RE in Asia-Pacific islands, 2009

In early 2009, I received a hard copy letter and a email inviting me to make a presentation on biomass based technologies for small islands in the Asia - Pacific region; islands like Kirbati, Timor-Leste, Tuvalu, Tonga, Vanuata, Samoa are the small islands. The reason for the interest on the part of US Navy was that they were significantly present in Okinawa Island from a long time and there was growing resistance for continued presence there. Therefore, they were looking to move into other islands in the region. And when they are in the region, they had some responsibility to upgrade the lives of the local population through renewable energy options using as much of local energy sources as possible. This appeared to me a perfect match between what I was advocating over a long time and the work we did in Port Blair (Andaman and Nicobar Islands). I was very enthusiastic in making my presentation and discussing and arguing with some navy officers and Japanese scientists attending the conference about this alternative and its various outputs - producing good quality fuel from various residues as a separate industry, high grade heat, good charcoal or biochar, electricity all of which needed many skills and hence job opportunities. I was heard with distant respect and was well taken care.

Kyoto is a beautiful city full of Japanese temples located with park space around. I walked in the evenings several kilometres all over seeing the parks around temples with very few people around. During some breaks we were shown several tourist spots in Kyoto. I had read about Kyoto through the books by Pico Iyer whose travelogue contains several sensitive observations of men and matters around the places he visited. This included Kyoto which is where is has been his home for around three decades.

(see if you like, https://www.afar.com/magazine/travel-writer-pico-iyer-on-life-in-japan)

4.25. Berlin summer school invitation, 2016

Prof. Ajit Kolar of the mechanical engineering department of IIT Madras had participated in the joint collaborative project on Advanced Biomass gasification at IISc in 1999 - 2002 supported by MNES. We were present together for a two day workshop with select senior scientists at Warwick university, U.K. to participate in Indo-U.S. programme on "Electric Power Technology Assessment" during 24-27 Sept. 1999. Later, he took charge as the principal Indian coordinator of Indo-German collaborative venture called Indo-German Centre for Sustainability (IGCS) at IITM. He had conducted some meetings at IITM and had invited me to present talks at these meetings. In 2016 (14 to 17 July), a summer school was organized by them in Berlin for which the participation was international. He had called me to present a lecture at this summer school. I agreed and both myself and my wife went to Berlin.

The workshop was interesting with visits to large biomass power plants - the 3000 MWe coal fired power station at Vattenfall and 20 MWe wood fired power generation system (Heizkraftwerk, Neukölln). The wood fired combustion system was interesting and unique. Of course, the system used as-received biomass, perhaps with moisture fraction of 30 to 40%.

At that time, my son, Dr. Shravan Hanasoge was a visiting Professor at ETH, Zurich. My daughter, Dr. Mythri Hanasoge and family lived in UK. They decided to visit Berlin for a few days (after my commitments at the summer school were completed) so that we could be there as a family and as tourists walking around the historic parts of the East and West Berlin. Also, we went together to Switzerland and spent a few days there as well before we returned to respective places.

BIOMASS GASIFIERS - RESEARCH, TECHNOLOGY TRANSFER, BIOMASS MAPS

5.1. The people I knew

I worked with the Ministry of Non-conventional energy sources (MNES) what became later as Ministry of New and Renewable Sources of Energy (MNRE) from 1984 to 2003 when I retired from IISc. Several Secretaries and advisors in Bioenergy division have been known to me and I was the co-chairman of the Biomass gasification committee along with Dr. Chaman Lal Gupta (CL Gupta at Aurobindo Ashram, Pondicherry). Two secretaries to Government of India at MNRE who stand out are Mr. Mukherjee and Mr. B. R Prabhakara and amongst the Advisors are Dr. K K Singh (KKS for short) and Ajit Gupta. One unique person whom I admired and with whom I was in touch for a long period was Dr. K. K. Singh. I have also known Dr. S. Khandelwal and Dr. N. P Singh at later times. Prof. A Ramachandran, first the chairman of Mechanical Engineering department at IISc, director, IIT Madras later, Secretary, Department of Science and Technology, New Delhi, and later as Head of UNHCC, another generous distinguished scientist-administrator was the chairman of the review committee of the major project from MNRE on bio-energy. There have been a number of industries wanting license for the manufacture of the gasification systems, a large number of investors and visitors I knew over a time.

5.2. The New Delhi meeting and afterwards

I received a letter from Dr. O. P. Vimal inviting me for a committee meeting to be held at the Department of Non-conventional Energy Sources (DNES which later became Ministry, MNES and much later Ministry of New and Renewable Energy, MNRE) sometime in 1985. By this time, we had already done several studies and developments in gasification systems for electricity generation. Dr. O. P Vimal was the director of bioenergy section. This was the first call from the ministry and I was not aware of him or his background till I attended the meeting. I met the distinguished participants at the meeting - Prof. P. P Parikh from the Mech Engineering dept, IIT, Bombay, Prof. P. D. Grover from the Chem Engineering dept, IIT Delhi, and Dr. B. C. Jain, MIT (US) trained graduate of Jyoti Industries, Surat and a few others from the ministry including one Dr. K. K. Singh of MNES who appeared observant and silent. The subject of discussion was the developments in gasification. I found the discussion many a time comical, several statements made were either incorrect or certainly doubtful. When the basis was probed, an obscure report or recent experience was quoted. It was clear that many who participated did not know the fundamentals of the subject. I drew an inference that it would be more difficult to deal with this group. I needed to be careful if we had to penetrate the establishment and make some useful contributions because the system appeared largely ensnared by some academics or associates. Because of my line of questioning, a bit more of whys, I must have been perceived as a volatile person or difficult-to-deal-with person or both. At the meeting I was asked if we could supply some number of systems for field trials on power generation from biomass in dual-fuel mode. I enthusiastically asserted yes. This was heard perhaps with some doubts in the minds of the members around. Having stated it, I looked at each of the members without batting an eyelid. They may not have appreciated the reason for the confidence in what I indicated particularly because Prof. Mrs. Parikh had indicated various technical issues with the gas quality involving tar and particulates. Dr. Jain who had already acquired Prof. Parikh as a consultant to M/s Jyothi industries could not disagree and it appeared that the ministry had to accept my statement based on uncertain trust.

There was considerable background to my confidence at the meeting. In March 1981, at the formal lunch associated with the “court meeting” of IISc (an annual event chaired by one of the members of Tata family and at this time, it was JRD Tata) arranged inside the quadrangle of the main library, Prof. A K N Reddy, one of my senior colleagues spoke to me and asked if I could undertake research and development of biomass gasifiers to operate diesel engines in dual fuel mode. I enquired as to why would this be important. He went on to explain that the country is facing shortages of diesel and this is hurting the farming community that needs to pump water for agricultural operations. Since diesel was expensive, the cost of pumping had become prohibitive. If we could replace at least 75% of the diesel by using biomass, he indicated that the farmers would have an option of reducing the dependence on diesel.

5.3. Merging with Prof. A. K. N. Reddy's vision

It is only appropriate to point out that Prof. A. K. N. Reddy formally belonged to IPC department, but in close cooperation with Prof. Satish Dhawan had started the centre for Application and Science and Technology to Rural Areas (ASTRA) with the aim of bringing together faculty for doing research and development relevant to rural areas in 1974. He also stated that he would send me a copy of the Swedish work on gasification summarizing the work done during the World War II years largely for me to get an idea of what it was all about. He explained to me that my expertise in combustion could be applied to the science and development - interesting way of enticing a younger colleague who is known well to be working in this area, I thought. Truly, I had not explored the field of combustion of solids and I had inner trepidation about whether I would be able to deliver. Nevertheless, the same inner voice told me to accept it and I did so. I said that since I was partly busy at that time with projects from ARDB (on hybrid rockets), I would accept it provided, Dr. Udupi Shrinivasa who was a research associate at the department would collaborate with me on this project. I spoke to "Udups" as we used to call him (later) and I guess Prof. Reddy also must have persuaded him and the result was this cooperative arrangement came to be in place. Prof Reddy had also created an organization called Karnataka State Council of Science and Technology (KSCST) which was a Karnataka Government supported outfit located within the campus of IISc and Prof. Reddy's vision was to speak to colleagues at IISc, identify ideas and projects of significance to rural areas, provide financial support to make formal proposals that would be considered for funding by the joint committee chaired by a prominent member of the Government and the director, IISc. I would say that these thoughts that he expressed to me clearly were so much more advanced compared to whatever was being conceived or done elsewhere in India that this became a model for many other state governments to adopt. That, several years after he retired and moved on, things were not in the best of state at KSCST is reflective of a natural order of decay that occurs unless periodic corrections are inventively made.

The project for Rs. 40000/- and for a period of 2 years was cleared and the finances were made available for building the gasification system. It was at this time I started reading about how biomass combustion works and what is gasification. The document that Prof. Reddy had given was outstanding and I studied many more articles and papers. I learnt that if I was asked a question as to how a liquid fuel burns, I could give along talk if needed, but had little idea of how things would happen with biomass. I must confess I felt ashamed that I did not know about how things happen with natural substances in wide use - for, most households in rural India used only traditional "Ole" or "chula" with firewood or other agricultural residues as fuels and I had very little idea of how and why of combustion. They were always called “fires” for the reason that air was drawn in by the process and there was no supply of air. The environment for general interest in these areas was also high in specific circles. Prof. Reddy had also created a centre in a village called Ungra about 100 km from IISc where several members of ASTRA could go, spend time, conduct studies, hold discussions for brief periods of time.

5.4. Collaboration with Dr. Udupi Shrinivasa

Udups had soon become a faculty member of Mechanical Engineering department and this facilitated formal functioning in collaborative mode significantly. Both of us used to meet towards the evening at rocket test house which is where we had a wider area for the conduct of solid and later hybrid rocket engine studies. During that period there were no other buildings around and we used to sit around the backyard and conduct experiments on stoves or hold discussions on larger issues of rural energy linkages with agriculture. Of course, chatting also included men and manners (or matters!). This was joyful period of learning. We started two parallel complementary activities - One was to build gasifiers and operate them to determine the issues and problems. An auxiliary one was to understand combustion of biomass and efficiencies of natural draft wood burning stoves.

The next five years saw serious research and development to understand the earlier work and complement it with the needed work to enable design of combustion systems as well as gasification systems. More arguments were found to say why gasification of solid fuels allowed better control on combustion, emissions, and ability to produce the starting "stuff" for chemicals including bio-fuels. While all the WWII systems were at larger power levels, we thought that the system design for small power level should be done with fresh thinking and not downsizing from the WWII design. For instance, the WWII systems had a huge top volume to carry biomass for some 4 to 8 hours and we thought we can feed as much as needed continuously and we should only concentrate on the crucial reaction zone - typically about 5 to 7 particle size height. This thinking process brought down the size to small levels. We put in ideas of water seal, an air supply system in the middle zone as well as from the top with thinking over a year, hardware construction and tests. Systems for power levels of 5 to 100 kWe were designed, produced using a local support fabrication facility and tried out in the field under a program of the Ministry of non-conventional energy sources. One of the early milestones was reviewed by a committee chaired by Prof. Dhawan after he had retired from IISc, vigorous and as clear cut as he was when he was the director.

5.5. Review by Prof. Satish Dhawan

My visit to MNES was sometime after the review of our work on gasification by Prof. Dhawan. I remember vividly one question that he posed - if large scale systems had been built elsewhere, what was the difficulty in following similar ideas on small scale systems. I explained to him that the larger systems were built during the WWII period and were in aid of replacing the transportation fuel, namely diesel and gasoline. The current contest is for stationary systems and the principles and ideas need not be the same. He did agree with this perception.

Thus, I had strong reasons to feel that our understanding was far superior to what was present during WW II. Sometime after I returned from New Delhi meeting, I got a long, well worded, provocative letter from Dr. K. K. Singh (principal scientific officer in MNES) whom I had not known much during the earlier meeting - there were too many people and I could not place all of them. In this letter, he invited me for a possible meeting in his office. I took this opportunity to go the ministry to specifically meet him somewhat hesitantly because it was difficult to imagine a letter of the kind I received from an officer of the Government. In fact, I entered an office and enquired if I could meet Dr. K. K. Singh (KKS) and he immediately responded that he was the person I had come to meet and motioned me to sit across him and we began the conversation. I complimented him on his well worded letter not usually expected from a traditional ministry, did he mean all that was stated in the letter - about how to scale up the program and what kind of major initiative would IISc be willing to take, etc, etc. He was incisive in pursuing the answer to the question of tar and particulates affecting the performance of the engine. I explained to him that we had done experiments for several hours at a stretch and we have run a gas engine as small as 1 kWe coupled to a pump in a field location for 24 hours continuously. He pushed me hard - could we stand up to a strong demand of setting up field level systems and provide technical support to successfully operate them. Noticing the uphill task he may be having because of the advice from other distinguished participants, I indicated to him that we could hold a meeting of all distinguished people at IISc sometime in about six months or so and hold discussions on various aspects after a demonstration of what I claimed as our know-how.

After I returned to IISc, we still had to overcome what I thought as a headache, namely the use of throat. Two things happened simultaneously at this time. Some engineering college students wanted to do a project - of significance - and the serendipitous arrival of a paper by Dr. T. B. Reed. He had chosen simply an open cylindrical reactor even without a throat or air nozzle in the middle of the reactor. This would precisely address our concern of deploying a throat that my burn off too often and hence, its avoidance would be a great virtue. The use of throat was just a kind of hangover from WWII design and it was simply that we had chosen not to be brave enough to dispense with it. To be sure, we built the new hardware and had the student group conduct experiments without the throat plate in less than a week and found that the performance was unaffected, in fact superior as the flame at the burner seemed to remain steady throughout the experimental period of two hours. It is amusing to know that we did not have any composition measuring system and while we did not take pride in this, we were not in the least hampered by its absence and other indications were available for deciding on the quality of the gas. The reactor for small systems was essentially a twin cylinder with an air nozzle around the middle. The inconvenience was that the air nozzle had to be welded both to the inner and the outer shell.

5.6. The 1986 IISc workshop

In June 1986, there was a workshop held at IISc faculty hall with about a hundred participants including the distinguished academia, participants from nodal renewable energy agencies (like KREDL, NEDCAP, GEDA, MEDA, etc). Presentations were made by technology developers like

Jyothi Energy Ltd, Prof. P. P. Parikh, Prof. Grover, Dr. B. C. Jain and myself and others from MNES. Towards the afternoon, visit was arranged to the Combustion, Gasification and Propulsion Laboratory (CGPL as it is called even now) where four different open top gasifiers were functioning with different biomass and one of them was connected to a diesel engine. Diesel replacement of 92% was recorded and shown to all the participants. Further, after the run, the air entry zone into the engine was opened and shown to be clean. Dr. R. Vasudevan of BHEL enquired if he could take measurements of the gasification system and I indicated that if this system goes to a field anybody could take these measurements and indicated that he could go ahead and take whatever measurements he wanted.

Clearly, the meeting funded by MNES was a run-away success and showed that the new technology of open top gasification systems had taken birth and was likely to grow. KKS sought a meeting towards the evening at the guest house and Udups, S Dasappa (SD) who had joined ASTRA working at CGPL, myself and Mr. Rajagopalan of KSCST spent some time. He wanted to launch a thousand gasifier program across the country and was intending to allot 400 systems to Karnataka, the project to be operated through KSCST. He enquired the status of production of systems, of training of operators and other related aspects as to how they will get managed, etc.

In anticipation of such a project, we were hunting for prospective licensees to manufacture the gasifiers in numbers and also get their team trained in operation and maintenance. One Mr. Joseph who was a furnace manufacturer showed interest in the technology transfer.

This was duly dealt with within the Institute and action to produce the gasifiers were begun. And as a requirement, an Indian patent for the technology was written up and was applied for.

Several of the early systems were tested at the laboratory with 5 hp diesel engines connected to electricity generation to enable control and monitoring of the output delivered even though the field applications were related to diesel engine pump set combination. Some six months later, the project got sanctioned and the order was placed by KSCST on Mr. Joseph's company. It took some two years for the supply chain and aspects related to local operational training to the prospective users to take effect. During 1987 to 1989, I was away on a sabbatical at NASA Langley research Center (LaRC) located at Hampton, Virginia. Though I was in touch with colleagues at the laboratory, it was for Udups, SD and PJP to take care of the activities. During this period, KKS came up with other challenges to be posed to IISc team because he found the team at IISc was looking forward to measure up to his expectations. He wanted a gasification-based power package to be put in Port Blair which depended on diesel electricity for its normal functioning. This has been so for all the islands - Andaman and Nicobar as well as Lakshadweep islands. He made a visit to Port Blair along with Dr. Vasudevan of BHEL to discuss with the Lieutenant Governor and the electricity department the deployment of both 3.7 kWe systems as well larger ones. Mr. Bhagat Singh, Manohar Singh and Mr. Nair of the electricity department got involved, KKS was well prepared with electricity and diesel and biomass resources data of the islands and persuaded (or made) them to accept his proposals for which he would sanction a project and provide financial support. While 3.7 kWe system was just for demonstration, he wanted the Chattam island saw mill located close to Port Blair to actually benefit from a 100 kWe power station using the waste wood pieces for power generation using a diesel engine in dual-fuel mode.

He returned to New Delhi and initiated two projects in a few weeks - to set up some 3.7 kWe or 3.7 kW pump sets at select places and develop an automated system for 100 kWe power station for Chattam island saw mill. Mr. Bhagat Singh and team of the island would erect and commission these plants with the help of IISc. The two major developments that took place happened when I was away in the US. The principal torch bearers of the action were SD (who would register for Ph. D via Mechanical engineering department) and Prof. Udups.

5.7. Initial efforts at Port Blair

There was a visit of SD and Dr. R. Vasudevan to examine the arrangement for 3.7 kWe gasification system and the possibility of a fluid bed gasification system for sawdust available at the Chattam island sawmill as well as the fixed bed system of 100 kWe based on IISc design that was still to be built and tested. The project of Dr. Vasudevan ran for about 2 years at BHEL, Trichy (which is where he was working), did not meet his own expectations in terms of gas quality and he then declared that system did not work and returned the unspent R & D money to MNES. During my life, this is the only project that I am familiar where the investigator has openly indicated that the project did not work and returned the money.

The 3.7 kWe system was built and shipped to Port Blair. The hardware was to be delivered to Chennai office of the electricity department and then it would be shipped by them to Port Blair depending on the schedule of the ship movement. KKS had decided that the 3.7 kWe system would need to be demonstrated to the Lieutenant Governor on a specific day. Some components had not yet arrived at Port Blair and the local workshop was slow in helping to put together the system elements. The concern about meeting the target date was not an imagined one particularly because it would be demonstrated to the highest authority on the island. SD was the only person on whom everything rested. Dr. Vasudevan was concerned if all things would go along as expected. KKS calmed Vasudevan and told him to watch. After some tinkering and adjustments, the engine operated in dual fuel mode and the demonstration was considered a success. Dr. Vasudevan was so overjoyed by the turn of events that he bought up a jackfruit and ate the fruits in the night!

Back home, suggestions were being made to the gasifier tested in a standard manner. We had offered one system to be tested at IIT Bombay for Prof. Parikh to test it at her centre which was sanctioned as a test centre for gasifiers. She had procured a large cache of equipment related to gasification although I could not appreciate their significance. Curiously, Dr. T. B. Reed who wrote on the world state of gasification at that time stated that what equipment Prof. Parikh had far exceeded what he had at Colorado.

The issue of testing had other contentious aspects. Unlike plug and switch on systems for liquid fuels, this system involving uncertain solid fuel quality in terms of size, shape and moisture fraction and needed manual intervention for feeding the biomass, certainly for all small systems of this size that were built with an attempt to make the product cost affordable. Our expectation for testing of systems from any manufacturer was that the system could be operated by the personnel of the manufacturer at the IIT B laboratory with appropriate instrumentation the arrangements for which the manufacturer would provide the interfaces. Prof. Parikh wanted the system to be delivered to her and no representative of the manufacturer should be there while testing. In any case, her viewpoint prevailed and one system was delivered to her by Mr. Joseph. She performed the tests and published a paper without indicating the source of the system and also not sharing the data with the manufacturer. Also, she would not even share the broad information with scientific collaborators like us. The data was treated as secret and “sacred”. We thought this was preposterous because all of us were in learning mode and it was appropriate for all to share and understand the results. In any case, the attitude did not change over time. We then offered to MNES that we would carry out the tests with a protocol similar to what was being done at IITB for some test systems where the manufacturer can send their team to operate the system while we will take measurements and share it with them soon after the tests. All these informal discussions were taking time and there was also an internal discussion in which it was thought appropriate to disengage from testing and be in developmental mode because that is where the challenges were.

5.8. The 100 kWe project for Port Blair

During this period, the project for the 100 kg/h system through KSCST was cleared by MNES. Also, MNES was holding meetings at various places to provide more opportunities for younger people to participate in the discussions and also evolve their own strategies for supporting the program. Two Ph. D students of Prof. P. D. Grover, Ms Anuradda Ganesh and S. Gaur were actively participating in the discussions. Sometime during later part of 1988, KKS supported the travel of SD and Anuradda Ganesh for a conference in Florida (US). During this period, SD came down to Hampton and spent two days. We had conversations of the scientific and developmental issues of gasification currently underway at CGPL.

Soon after my return, in June 1989 from the USA, I was to examine the development of the 100 kWe gasifier-engine system. On the gasifier front, it was clear to us that should move from metals to ceramics as high temperature material. We explored several options and inferred that an outer metal casing was essential in order to stabilize the construction. Further, water seal was adopted for the top fuel loading region and the top cap would be opened during the operation and closed during shutdown. The bottom region also was initially made of water seal. This got changed later to a covered screw extraction design after considerable testing and understanding of the material movement aspects.

During this time, Dr. N. K. S. Rajan had been drawn in particularly because the final system had to have a control and data acquisition system - he was the electrics man in the laboratory. It was intended to present the data on electrical output delivered, diesel flow rate and diesel replacement on a computer. The gaseous fuel admission into the air stream had some complex elements and I had to intervene to simplify this into a simple T junction with motorised valves for the fuel gas side to enable control of gas fuel admission. Two aspects that were recognized were that (a) gas would mix with air in passage through complex passages and valve finally and (b) the diesel spray in the engine had to get ignited and burn in diffusion flame mode. The inference was that the engine is anyway experiencing diffusive mode of combustion and hence complex mixing arrangements had little functional role.

The hardware including electronic items was ready to be shipped by the beginning of 1990. The shipment was arranged through Chennai and information came that the hardware had arrived at Port Blair. The responsibility of Port Blair team was to complete the civil works. When enquiries were made on the status of civil works, we were told that they were in advanced stage and detailed information was not available. The team from IISc consisting of technicians reached Port Blair. They uncovered that very little had progressed. For some time, IISc staff were being used to advance the civil works. After tolerating this for two weeks, it was decided that the team should return to the laboratory and only when the entire civil works was complete, they would go to Port Blair. It took several months with calls from IISc and New Delhi before the system was to get ready for commissioning. The assembling team went to Port Blair in September 1990 and the team which was fine tuning the computerised data acquisition along with some of us reached in December 1990. From MNES, Mr. Joshi, Advisor and an SSO named Srivastava came (By this time, KKS was an advisor). By this time Mr. Bhagat Singh had left the organization (we were told for uncertified actions) and Mr. Nair was the local go-to person with Manohar Singh in charge. The power generation system had some initial hick-ups and when they were sorted out, it worked well at diesel replacements of 70 to 85%. The system was delivering a load of 30 to 60 kWe and when the load increased by 30 to 40% in as short a duration as half a second due to large welding system currents, the power generation system was delivering the output without any issues. The system inertia was adequate to deal with the fluctuations even at 80% diesel replacement. The computer monitor was displaying the information on the electrical load and diesel used and diesel replaced. Towards the end of the day, the data on wood usage would be entered into the data acquisition system to enable obtain an estimate of overall biomass to energy delivered. The value varied between 0.9 to 1.2 kg/kWh. We (Udups, SD, NKSR, PJP, Rajagopalan of KSCST and myself) were overjoyed with the performance. Mr. Srivastava chose to sit at the terminal and watch the data flow for several hours at a stretch. While MNES seemed pleased, they did not seem “zapped!”. We inferred that even to appreciate the enormity of what had happened, it would take some appreciation of the technical stuff that led to this exciting performance. This system functioned for several years and a few members went to Port Blair maintain the system on two occasions. Beyond that, our role got diminished and, in the meantime, other things on the mainland drew our attention.

During our stay we visited two islands, Kings and Ross. The structure in King's island had such overgrown web of branches and roots on a building that we thought it would only be a few years when the biomass would crush the structure and natural growth would cover the entire region. We did some snorkelling on Ross Island beach and saw jelly fish - almost invisible!

A biomass gasification technology group was created by MNRE with Dr. C. L. Gupta (associated with Aurobindo Ashram and having a solar energy centre at Pondicherry close to the Ashram) as the chairman and me as the co-chair. This group was supposed to hold meetings and assess the progress of the technology in the country. Several more centres were created - one at Madurai Kamaraj University with Prof. Haridasan (with a Ph. D from the Physics department, IISc) and action research centre at IISc and continued testing at IITB. There were two conferences in 1991 (at Baroda organized under Gujarat Energy Development Agency, GEDA) and 1992 (Jayachamarajendra college of Engineering, Mysore with support from KSCST). In the years to follow, further consolidation of the efforts in terms of internationalizing the knowledge base took place. Three international training programs were conducted at CGPL. These were attended by scientists from a dozen countries both east and west. In one of these training programs attended by participants from Brazil, Thailand, Zimbabwe, Kenya, Nepal, and Srilanka with some of them supported partly by MNES, the team visited the 1 MWe biomass power station owned by Arashi Hitech biopower at Coimbatore. It was one of the very enjoyable trips that the hard-working team at CGPL had in the company of an international group. Half a dozen students came from overseas to spend months for familiarization, training and research studies. Technologies were transferred to eight licensees in India and two overseas.

5.9. Field outreach - small gasifiers - water pumping

The 400-gasifier project initiated by KKS was implemented by KSCST and its staff located in various districts were sending in reports on the installation, commissioning and operational aspects. In the first round of installation, there were issues of lack of training and in several cases, the identification of the participating farmer was not quite appropriate. They were using the diesel engine in diesel alone mode and it was discussed with MNES and based on their input it was told to the users that if they do not use the gasifier, the system will be moved away to another user. Interestingly, there were occasional glowing reports of 75% diesel replacement in many installations. We wanted to visit some of them to evaluate the true situation. Four of us - Udups, SD, PJP and myself went on a gasifier yatra. Locations were identified earlier by KSCST and one representative would help us locate the specific user because the location in some instances was very remote and difficult to access. We had a taste of what real life was all about! In one location near Sirsi (North Karnataka) they were saying they produced stones from the gasifier and it appeared bizarre! We reached the location towards the evening and staying through the night there. We examined the system and the biomass used. They stated that they were using biomass from trees in the forest. We examined the biomass. We saw that there was white ant attack and small holes were seen filled with mud. We inferred that it is the mud that would have melted because the material would have lower melting point (the saliva and other biological fluids would provide potassium that helped reduce the ash fusion point. Having inferred this and described to them what we thought the issues were, they received our explanation and wanted a demonstration. We were served dinner and then the gasifier was started. We began to look at the wood pile and separated clean pieces from those with termite hit material. This became the feedstock. After a run for 3 hours during which we must have used about 12 kg of biomass feed. Then, we shut down the system, waited for 30 minutes and then extracted the bottom ash. It did have some tiny stone like pieces but much less than what they thought they would get. I think they figured out that this was no mystery, but simple science and left the matter at that. We slept off at about 2 am for about four short hours.

In another location between Hassan and Sakaleshpur, the user stated that the system was working wonderfully well. The first check point for the use of gasifier would be the engine air filter through which the gas-air mixture would have to pass through. The air-filter looked very clean. We knew that they must not have used the system. After checking the flexible plastic piping that was provided to them, we found that the gasifier to the engine line had a disconnection. The gasifier itself was functioning well on blower mode. After all this was explained to them, there was a sheepish grin. It turned that they were really not intending to do the mistake, but were unaware and presumed that they should not complain about what was given free!.....interesting, it was.

In a third location, the user wanted to reduce the job of cutting firewood into smaller size pieces and had invented a procedure of using longer firewood pieces introduced vertically. Explaining the problems associated with this change was trickier. We explained to him that when short pieces were loaded the flame has difficulty in jumping from one to the one-above. However, if longer sticks were used, the flame would happily creep towards the top even with a small flow of air in the opposite direction. In case the system was shut down and was started again the flame would have converted slowly the biomass into long pieces of char and this was not a desirable feature.

The Yatra of a week was a very enjoyable one apart from being educative.

5.10. Biomass gasifiers for electricity in villages - India and overseas

The idea of biomass gasifier-based electricity generation started during interactions with ASTRA that had a centre at Ungra, a village in Kunigal taluk, Tumkur district. There were occasions we would visit this centre to educate ourselves with the issues that bother the villagers. Dr. N. H. Ravindranath of ASTRA was spending time there taking care of the centre those days. Later he became a faculty member at ASTRA and also at the centre for ecological sciences. After discussion, we felt that we should do field level experiments that improved the life in the villages based on the expressed needs by the villagers themselves. There was a number of unelectrified villages in Karnataka around that time. This included the villages around Ungra. The reason for the choice of a village near Ungra was simply based on logistics. After interactions with the Karnataka Electricity

Board (Karnataka Power Transmission Corporation Limited, KPTCL now), one hamlet called Hosahalli about 10 km from Ungra was chosen. This became the stepping stone for village electrification projects. As awareness of the experiment spread, a large number of administrators,

industrialists, entrepreneurs and villagers began frequenting the laboratory and other field projects became possible. To manage the operations technically and managerially, Mr. S. N. Srinivas got recruited to help the project. Subsequently, he moved on to Tata Energy Research Institute (TERI) where he also got his Ph. D and later to UNDP. In what I am describing, my role was limited to discussions before the initiation of the project, help tending to teething problems and other major management issues that could come up during the operations as they indeed did. My colleague Prof. S. Dasappa who belonged to ASTRA handled many interface issues with other colleagues who would visit Ungra and Hosahalli more regularly. Whenever major problems were to be resolved all of us together went to the village and had meetings with as many elders of the village as possible attempting to resolve the issues. Village level politics could be far more complex with one face seen at formal meetings and another on ground level operations. I treated these efforts as more of learning exercise rather than provide permanent solutions because too many players were involved and we had no authority over several of them.

5.11. Hosahalli near Ungra, Karnataka

A hamlet, 130 kms from Bangalore, that had 43 families with about 200 inhabitants, 95% of whom were illiterate, had remained unelectrified in 1988 and was chosen for electrification for illumination of all the houses initially. This was based on a 3.7 kWe gasifier-based dual fuel operating diesel engine. The required biomass for the plant operation was obtained from a 2.5 Ha plantation that was specially grown for this purpose. The gasification system used was a twin stainless steel shell system. This worked for the entire year for 1200 hours and the reactor had to be replaced at this stage. In about two years from the start of the operation, the load demand had increased to 5 kWe with actual demand estimated at 6 kWe. During this period, the demand of the villagers for drinking water also was fulfilled by operating the system during the day when electricity for lighting was not needed.

Subsequently, a flour mill was also added to improve the plant load factor, which was at 15%. For about a year, the system was operated with a number of problems in which the system breakdown occurred due to overloading and inadequacy in meeting the demand, and these led to societal issues. A new project was sought from MNES to upgrade the system to 20 kWe and so the gasification system was also changed. This system provided electricity for lighting, drinking water supply and flour milling facilities. The system was run for three years in this mode. Subsequently, a new version of 20 kWe system was installed to cater to additional services like the irrigation in April 1999, which has incidentally turned out to be more remunerative. The power package consists of a reactor – lined with tiles, gas cooling and cleaning system –with sand filters, D-G set and a biomass drier.

It was found that the tariff collection was barely adequate to meet the running expenditure. There were several other societal problems like, persons from neighbouring village cutting large tree trunks for personal benefits. This led to tensions that needed the local forest administration to intervene. When similar incident occurred a second time, the villagers caught the illegal shipment red-handed and handed them over to the police. This led to a situation that needed careful man-management. The primary issue of power plant management had many such distractions. The project was continued since some critical issues had to be understood and resolved. These related to economic operation of the power plant in a sustainable mode. It was found that irrigation water provided opportunity to pump water so that the saleable commodity was water and not electricity. This provided returns to a level twice to thrice of classical electrical tariff. This called for careful planning of the piping system involving flexible piping elements so that they could be withdrawn, if necessary. This operation was begun towards the end of 2000. Several landowners have taken advantage of this facility. The experiment continued till about 2003 and did not proceed further since KPTCL came up with electrification of the village. The power plant completed nearly 6000 hours and generated about 62,000 units of electricity in four years of operation. Of the 6000 hours operation, dual-mode of operations accounted to nearly 75%. During later periods, the day-to-day operations were managed by the Gram Panchayat, with the plant being operated by the local village boys.

5.12. Hanumanthanagara near Ungra

Hanumanthanagara, a village 4 km from Hosahalli, with 50 houses and 250 people on the bank of the Shimsha river (flowing at a lower level) receiving grid electricity wished to have services similar to Hosahalli, essentially since grid electricity was poor. This project was designed using experience gained at Hosahalli. A 20 kWe gasifier-based DG set was installed in 1996. System performance was comparable to Hosahalli in terms of services. The power package comprises of reactor – with ceramic mass lining, gas cooling and cleaning system – with sand filters and a D-G set. The system was operated 5-6 hours per day, providing services such as drinking water, illumination, and flour mill. The system completed 4500 hours and generated about 27,000 units of electricity in five years of operation. Of the 4500 hours operation, dual-mode of operations accounts to nearly 70%. The day-to-day operations here again, were being handled by the local village boys with entire project operations was being subsidized.

Other experiments related to irrigation were tried out in Palarayanahalli, a village is 10 km from Hosahalli was established at Ungra in 1993. This experiment did not proceed beyond a point since the number of participants was limited.

5.13. Dewan Estate, Kolar, Karnataka

A farm estate located 80 km from Bangalore in Kolar district was owned by a church father, Father Jovita. A 50 kg/hr gasifier was installed to supply gas to one diesel engine of 20 kWe and another a 100% producer gas engine of 16 kWe capacity. The system comprised of a reactor, gas cooling and cleaning system – with sand filters and engine-generator sets. The system was operated for more than 2 years with total operating hours of 2100 hours. The power generated catered to irrigation water pump sets and illumination of staff quarters. The system was operated whenever in need of irrigation water, typically for 3-4 hours per day. The plant was manufactured and installed by M/s Netpro Renewable Energy (India) Limited, Bangalore, one of the Indian licensees of IISc technology. The diesel-generator set was normally utilized for the gasifier start-up and once the combustible gas was generated, the gas engine was started and diesel-generator shut-off. Both the engines had a cumulative operating hour of about 3100 hours, of which the gas engine has operated for nearly 1400 hours. The number of units generated was about 38,000 kWh of which nearly 55% is generated using 100% gas engine.

5.14. Butachaques Island, Chile

The plant was meant for electrification of a village called Metahue located on the island of Butachauques, South Chile. This was joint project executed by IISc and UNDP-Chile. The total number of houses was 90 with a population of 900, all Spanish speaking, employed mostly in agriculture, aquaculture, particularly on Solomon fish farms; the village had a health centre, community hall and a government school. Most people had individual gasoline driven DG sets or batteries charged once in a while. Use of electricity was mostly for illumination, TV sets; while cooking was based on bottled gas and firewood. Approximate expenditure per family during winter on electrical energy is 70 USD. A 2 x 25 kVA DG set system was electrically synchronized and fed into the grid at 8 kV and reduced to 220 V using a step-down transformer at the user end. The unit comprised of a reactor, gas cooling and cleaning system – with sand filters, D-G sets, biomass processor, drier and a synchronizing control panel. Twenty-six houses were electrified and permitted to use electricity for illumination with fluorescent lamps, refrigerator, washing machines and water pumps. The peak-load was determined to be 10 kWe and the electric supply was used for five hours a day to be extended to about eight hours in winter. The measured diesel replacement over a five-hour cycle was 82% with a fuel wood consumption of 1.0 kg/kWh. The operation, distribution and tariff collection was managed by the village cooperative. The tariff estimate was set at 40 USD per house/month. The system had clocked in excess of 2500 hrs of operation and generated about 60,000 kWh till March 2001 for which time the project was tracked. It is at this installation that Mr. G. Sridhar and H. V. Sridhar along with Venu, the technician spent a month in the installation, commissioning and training of local operators. Chapter 20 contains the details of their activities on these aspects.

5.15. R & D on producer gas-based engines

It is important to discuss the power generation issues. In the early stages, water pumping from 5 hp diesel engine - pump set was the primary target - to provide diesel replacement of a value exceeding 75% using locally available biomass. Soon enough, it became transformed to generating electricity, again from a dual fuel operating 3.7 kWe diesel engine-alternator. A little while later, questions were asked: Can't we run the engine without the diesel. This was important because the diesel prices were going up and the cost of electricity generated even at 80% diesel replacement had a significant component from the diesel consumed. There was always a user tendency to run on diesel on a longer start-up and shut down sequences making the diesel consumption worse. This led to use of gas engines. The gas engines were not available easily. There were several options. One was to convert the diesel engines to operate on producer gas. The knowledge at that time was that we had to reduce the compression ratio from the classical 17 for diesel engines to about 10 to operate on producer gas to prevent knocking. We did some preliminary work and beyond that we did not get on to this task since we were very busy with many other developmental activities. Further, I also wanted some project to be provided to Dr. A. Ramachandra who was at the Jayachamarajendra college of Engineering (JCE), Mysore and so persuaded KKS to provide a project to convert a diesel engine to a gas engine, operate it with IISc gasifier and test its performance. After due process, this was done and Ramachandra got the project and conducted the necessary studies. Finally, he could operate the system on producer gas at its nominal rating with a compression ratio of 17. This became a milestone in the research and development activities on gasifier-based power generation. This was in fact demonstrated to the conference attendees of the biomass conference in December 1992 at Mysore.

G Sridhar became a research student of IISc on this problem on which he began working even before he became formally registered. So, he set about changing the head of a 28 kWe Kirloskar water-cooled diesel engine with gaskets to reduce the compression ratio and use the diesel injection arrangement. This study was something I was eagerly looking forward to almost every day since it is was excitingly new to the subject because literature was replete with statements describing de-rating of the engine output by 25 to 30% for moderate power producing engines. Experiments showed that the engine was working smoothly even at a compression ratio of 17 and its power output and efficiency improved with compression ratio. Final tests showed a derating of 12% that cannot be considered large because most engines are expected to operate at near 80% load for enhanced life. This study turned out to be a milestone since there was considerable misunderstanding in the literature that converting diesel engine to gas engine could lead to significant derating. Our own conclusion was that most systems would have operated with poor gasifier designs and it was inevitable that power generation performance would be affected.

5.16. Gasifiers for high quality thermal applications

Over a time, visits to industries and discussions with visiting industrialists showed that there was considerable benefit for industries to use biomass based gasifiers as replacement to diesel or furnace oil based combustion systems since techno-economic analysis showed that the payback was less than six to seven months at most. Industries that adopted them included M/s Crumb Rubbers, Palakkad (Kerala), Comorin polymers, Nagercoil (Tamilnadu), Agro-biochem (India) pvt Ltd, Harihar (Karnataka), Synthite Indistrial Chemicals pvt Ltd, Karamadai (Kerala), and M/s Taminadu Heat treatment and Fettling Ltd (TAHAFET), Hosur (Tamilnadu). While M/s Crumb rubbers was devoted to drying rubber latex, Agro-biochem and Synthite Industrial Chemicals were devoted to drying marigold flowers to produce an oleo-resin called Xanthophyll used as a feed material for chicken.

Drying of marigold flower, a low temperature application was considered to replace diesel fuel in the range of 125 – 150 lit/hr. Gas from the 500 kg/h solid biofuel gasifier system would be piped into the producer gas burners fixed in the combustion chamber with the downstream process similar to the diesel burner, implying mixing with air to produce hot gases at 100 to 120 $^\circ$C to help drying. In the case of Agro-biochem industry did not use any fuel oil over continuous nine months of operation. The example of TAHAFET is brought out below for the interesting problem they faced.

5.17. Project at TAHAFET, Hosur

One of IISc's former students had an industry in Hosur close to Bangalore called Tamilnadu heat treatment and Fettling limited (TAHAFET) performing heat treatment of steel components using furnace oil for the furnaces. They had quality problems with the product of heat treatment when furnace oil was used because of sulphur dioxide related corrosion and were seeking to replace the furnace oil by producer gas that is naturally much cleaner than the products of furnace oil combustion. The industry was meant for high temperature application in a heat treatment furnace in the temperature range of 600 to 920°C. After initial discussions we suggested to him to get the hardware built and guarantees on performance provided by one of our licensees, BETEL Pvt Ltd (Bangalore). The gasifier of 300 kg/hr of biomass consumption replaced 1500 liters of diesel or LDO per day completely. This gasifier with high quality gas (minimum particulate and tar emissions) was to be piped for use in 16 burners on 8 furnaces with each furnace operating at different temperature for heat treatment. The system design was such that the furnaces could be switched into furnace oil if the gasifier did not work by any chance to ensure non-stoppage of production. A message came through our licensees that the user is complaining about dripping tar from a control diaphragm containing valve (!), and so the stoppage of the system. Both Prof. P. J. Paul and Dr. S. Dasappa rushed to Hosur (only a 2-hour drive). They studied the point of leakage, smelled the dripping liquid and found that it was much unlike tar. On a careful examination and querying of the operators, it turned out that the operators were cleaning the diaphragm with turpentine. The turpentine was reacting with the material of the diaphragm and producing the problem creating liquid (!). The user and his team were provided the explanation and told that they must trust the new gasifier more than their old habits of maintenance! The systems operated typically 140 hours per week on a nearly non-stop operation for over 4000 hours of operation replacing fossil fuel completely in one year.

5.18 The transition - UNCHS meeting

In early 1993, there was a meeting of UNCHS (United Nations Centre for Human Settlements for which Prof. A Ramachandran was the head around that time) at KSCST located at IISc with specialists from several countries attending the meeting. Some of the experts were Dr. K. K. Prasad of Eindhoven (who was earlier at IISc as a professor for long time), Holland, Dr. Stephen Joseph from Australia and Dr. Hari Sharan from Switzerland (he was the head of R & D in BHEL for considerable period of time). We from CGPL were given a 15-minute slot to make a presentation of the progress on gasification at our laboratory. During the discussion, Stephen Joseph was arguing for steam power generation at small scale that sounded ridiculous because it could promise conversion efficiencies of 1 - 2% compared to 8 to 9% that we had got from 1 kWe gas engine. Dr. Sharan who knew the field of steam power generation like the palm of his hand spoke strongly and ridiculed the suggestion of Stephen Joseph. Since I had not known Dr. Sharan earlier, I must say, I was impressed by his stature and the nature of arguments.

Subsequent to this meeting, he visited our laboratory and saw in detail what we had done. He indicated that he had seen many developments in Europe with significant claims, but with few published details. He enquired whether we had publications in open domain and when stated in the positive, he enquired if we were prepared for a rigorous test of the gasifier for its efficiency and cleanliness - P & T results - particulate and tar on which we had great claims. We indicated that we were happy and ready for the tests according to the European protocol. After a month a half of back-and-forth discussions and an initial statement of the requirements for the test from our side in terms a upgraded hardware for a 100 kg/h system, and instrumentation, Dr. Sharan met with the officials in Bern (where Swiss government is located) and got the clearance for the tests on our system with a Swiss team to participate in the test.

5.19 The visit of Swiss Engineer

After this event, one engineer, Mr. Hans Kauffman who was pursuing his degree at ETH, Zurich was identified to visit us and finalize the details of the test. When he landed at the laboratory, he was very unsure whether the system would work at all and whether we would provide him with the details necessary for him to provide a go-ahead. His lack of confidence in the satisfactory working of the system arose from his experience with many private European systems that were not good at all and some, where the claims could not be rubbished so easily, the details were scanty and the people connected held the data close to their chest. His initial scepticism was quelled by him standing at the biomass loading platform and observing the movement of biomass during its operation. He noticed that there was hardly any person around the gasifier, the flame was burning in the burner and the biomass was sliding down the vertical cylindrical SS - ceramic reactor quietly. After overcoming his initial inhibitions, he opened his laptop and sought answers to several queries. When these were discussed with our colleagues, PJP, SD, NKSR, G. Sridhar (S2) H. V. Sridhar (S3) in sufficient detail, he developed warm and a mildly respectful attitude towards the scientific colleagues at the laboratory. SD, S2 and S3 became close to him and they went out to eat Indian spicy vegetarian food. Occasionally PJP would join in to help out with non-vegetarian food as well.

By this time, we had identified the testing laboratories where P & T analysis would be conducted. Dr. Bhat formerly of IISc was a partner in the testing laboratory called Cosmic Industrial laboratories. Dr. Bhat desired that the test procedures intended to be adopted be made clear to him. When this was explained by Mr. Kauffman, he indicated that he would get the necessary equipment and procedures for test implemented at his laboratory. The clean gas quality claim by IISc had its concomitant features related to test schedule. Most experiments in Europe were conducted with gas flow rate of 0.5 m3/h drawn from the gasifier for about 15 minutes. Because our P & T levels were claimed to be about a percent of the European systems, the test protocol was arranged to draw 2 m3/h of gas both at the hot end and at the cold end and for at least 5 hours under steady operating conditions - outside of star-up and shut-down periods. This implied that about 10 m3 of gas had to be processed for the hot and cold ends. The extraction of the gas from the hot and cold sides were to be done by a procedure called iso-kinetic sampling, implying that the velocity at the nozzle sucking the gas would need to be the same as the mean velocity in the pipe. This helped that the particulate content in the extracted gas would be the same as in the main stream. The gases would be drawn by suction through a train of glass containers cooled to very low temperatures in a bath of ice + salt mixture to cool the gas, drop off moisture, and then, through specific solvent and another empty bottle to drop off any solvent drops and finally very fine pore-based filters before being taken into burners for combustion. The solvent to be used was the subject of some discussion. The Swiss group chose methoxy benzene (also called anisole) that was considered a better alternative than many others in being able to dissolve many complex chemicals of tar and had a boiling point of 120°C and hence would itself not evaporate away from the system over long hours of gases bubbling through it. This liquid was maintained at 4 to 10°C so that most chemicals could be captured.

After settling the details, he returned to Switzerland.

5.20. Gasifier tests at CGPL with Swiss scientists

The system fabrication, procurement of equipment and instrumentation for temperature measurements, gas flow rates, biomass loading arrangements, the procurement of biomass itself took several months. Instrumentation for gas composition consisted of a gas chromatograph for methane, CO and H_2, a non-dispersive infra-red instrument recorded the carbon dioxide and an electrochemical instrument recorded oxygen in the cold gas. The gasifier was tested with wood chips (casuarina) of 50 - 70 mm long and about 25 mm in lateral size and in a particular test with a mixture of 50% of the above size along with small twigs of 1-10mm diameter and 25 - 75 mm long with 5% saw dust at three gasifier throughputs, full, one-half and one-third, the full throughput being set at 55 kg/h after initial tests. The biomass was sun-dry with moisture content were in the range of 10-12%. Though a total of 9 tests were carried out, six tests were conducted every alternate day with the Swiss team being present. The Swiss team consisted of Mr. Rudi Buehler, Dr. Phillip Hasler, Mr. Hans Kaufmann and Mr. Robert Mossier. Rudi Buehler had a private industry and therefore was an industrial partner and observer, Hasler and Kaufman were academics from ETH, Zurich and Mossier was a water expert from the canton (area) near Winterthur close to Sauzach, the place where Dr. Sharan lived. Dr. Hasler was a tar expert - of sorts. Mr. Kaufmann acted as an inspector noting down all the events and actions. Thus, whenever biomass was to be loaded or flow rate through the hot or cold P & T line was reset back to the original value, he would be brought in to show the reading and altering the suction level to ensure the flow rate to be nominal.

Tests would begin at about 8 am with IISc team consisting of four technicians and some of us. The Swiss team would arrive after their breakfast at around 8.30 am and would be seated in front of the gasifier on chairs around a large table. At around 9.30 am, the sampling would begin. During the day, they would each walk around the system and make their own observations. Around 11 am, they would get fried south Indian snacks - Pakoda, Vada and other items along with tea. A part of the team would adjourn for lunch a little earlier at around 1.00 pm and return. The test would continue without interruption till about 4 to 4.30 pm. The sampling trains would then be shutdown. The connecting P & T lines to the reactor would be disengaged, the material deposited inside would be washed down with anisole and collected into a container. The entire process had to be carried out delicately by the technicians. Dr. Bhat of Cosmic labs would arrive at around 6 pm, take representative samples of the cooling water to determine its contaminants and also the various bottles containing the dirty solvents for analysis at the laboratory. The entire process would take another hour and the Swiss team would get back to their rooms only afterwards. The next day was a free day and we arranged for their day-trips to various places within and outside Bangalore. This process continued during their stay. They stated explicitly that they were deeply impressed with the outstanding functioning of the technicians who virtually dealt with all that was needed for the system. Towards the end of the tests, I invited our director, Prof. G. Padmanaban to visit us and meet with Dr. Sharan and other Swiss scientists who had come to for the conduct of tests. Brief speeches by all around with high tea was the concluding segment of the tests.

It took four weeks to assemble the results, study them and put them into appropriate format. The results of these rigorous tests were truly impressive. It is appropriate to state that no other gasification system in the World had or has undergone such a rigorous third party-overseen test over a range of parameters. We had accurate numbers for cold gasification efficiency (of 82% at full load and lower at one-third load), estimate of undesirable chemicals in the effluent and most importantly, particulate and tar content in the hot and cold streams. Both the hot and cold stream data are considered important because the values provide input for gas clean up systems, whether more was needed even beyond what was provided.

5.21. Defence of the IISc joint test results in Switzerland

The report was prepared and sent across to Dr. Sharan as he was the technical and financial coordinator of the project. He desired that I go over to Switzerland and defend the results before their gasification community.

The P & T content under hot conditions seemed independent of the throughput, a result that was at direct variance with results of closed top systems where the tar was expected to be much higher at lower loads due to inferior thermal environment. These results surprised even the Swiss counterparts. The major difference between the open top, re-burn system and the closed top system was that the open top provided for much less fuel rich gases while coming down towards the air nozzle where some of the rich compounds were burnt again raising the temperature so that the endothermic gasification reactions proceeded better. In fact, so much better that the gas composition was close to the equilibrium value for temperatures of about 1000 K. This could be stated differently: the residence time for the reactions was adequate to go to near completion.

Dr. Sharan wanted me also to give a general talk at Chatel St-Denis where it was intended that a gasification system similar to the one at IISc would be set up for the Swiss community to do their own tests. Both these were accomplished in June 1995. I arrived in Zurich and had a hotel accommodation next to Winterthur railway station. This was the first time I visited Switzerland (there was one more visit along with my colleagues, PJP and SD subsequently). During the talk I gave at ETH, Zurich, I presented the unsurprising and surprising results of the tests and what they meant. There was an interesting incident during the talks. Before my presentation, there was another presentation by Dr. Henricksen, scientist from the University of Denmark on straw gasification using a screw arrangement with recirculation of hot gases on the outer region. The system appeared complex from the description he provided and I could not help asking him if a Ph. D was required to operate the system. This evoked laughter all round. I knew what I did was a dangerous ploy as it would rebound on me when I gave the talk. Sure enough, when I spoke of our gasification system and the experiments on it, somebody in the audience suggested that I answer the question I raised earlier but with regard to our system. I smiled and stated that I expected the question, but not so much that I should have a slide on it! I said that in the last six years, a 3.7 kWe engine on dual fuel mode has been functioning in an otherwise unelectrified village (named Hosahalli, implying new village, about 10 km from Ungra, the IISc centre) with village hands trained at our laboratory as well as in the field. I may also say a fair number of the village folk are barely schooled, but smart otherwise. Running a 50 kg/h system was simpler in several ways. The lecture went off well.

I had a dinner appointment at Dr. Sharan's residence the day following the lecture at ETH. The home had a cherry tree with sweet and wonderful cherries (this was the first time I had eaten cherries). I must have consumed a large number of cherries and little formal dinner!

5.22. Biomass conference at Banff, Canada

After the successful third party examination by Swiss scientists in the rigorous tests at the end of 1994, and several meetings that took place in 1995 and 1996, Dr. Sharan wanted a joint paper to be written up on the subject. Subsequent to this, I drafted the paper along with my colleagues at CGPL and we sent it across to Dr. Sharan. He submitted it for the conference on Biomass conversion technologies. He apparently, could not attend the conference and wanted me to attend it on his behalf. For this reason, in the middle of 1997, I had gone to Banff, Canada to attend the conference. I met with Dr. Tom Reed, Dr. Tom Miles and other distinguished scientists working on biomass technologies. My presentation was very well received and there was much discussion on the results that seemed so clear and somewhat uncharacteristic of the field where secrecy of the results on tar and particulates was the standard practice!

H. Sharan, H. S. Mukunda, U. Shrinivasa, S. Dasappa, P. J. Paul, N. K. S. Rajan IISc-DASAG Biomass Gasifiers: Development, Technology, Experience and Economics, Developments in Thermochemical Biomass Conversion, pp 1045--1057, Blackie Academic and Professional (Pub), 1997

5.23. The second phase of Swiss collaboration

Dr. Sharan managed to get a second phase funded to put up a system similar to the one at IISc for tests to be conducted by the joint team on European pine chips. There was a need to put in more automated controls (using a PLC, programmable logic controller) with the system. Putting together and shipping the system was a stupendous effort. While the glassware required for P & T testing was taken by SD with considerable difficulty, the electronics package was not packaged properly to withstand the sea environment during the long passage from Chennai to a port in Switzerland. This led to periodic malfunctioning. Dr. Dasappa, Mr. G. Sridhar and a person named Girish along with a technician (Mr. Tirupathaiah) went to Switzerland in the winter of 1996. They actually spent a month in January 1996 at sub-zero ambient temperatures even in the test area. They had to remain well clothed in the laboratory as well. SD related an interesting conversation with a Swiss company owner (producing tools and other machinery) who had run WWII gasifiers. When told that such a gasifier is being installed and what it will do, he disbelieved it and asserted that European pine could be gasified well. He was told that he could visit the facility when it running. Indeed, he did visit and expressed surprise at the smooth operation of the system.

The gasifier was operated at various moisture fractions up 30% and P & T measurements were made and the samples were analysed in three laboratories including one in India to verify the quality of the results. The results showed a substantial drop in efficiency with moisture fraction. The implications of these results (that were foreseen largely by IISc team) were to be realized by the European biomass community that was keen on direct thermal conversion of as-received biomass at reasonably high moisture fractions. That such an effort would be equivalent of double taxation. The calorific value of the input biomass is lower and one would not be able to expect a reasonable calorific value of the producer gas (compared to that from sun-dry biomass); further, the inferior thermal environment did not convert the products of combustion, CO_2 and H_2O into as much of CO and H_2 as would have been possible with a normal thermal profile inside. This would reduce the gas quality even further. That it is much simpler to use low grade heat ~ 100°C) to dry the biomass from values up to 45% to sun-dry conditions (8 to 12%) did not seem attractive for European gasifier developers. Similar arguments apply for biomass combustion systems. Most operators seem to think that drying takes place anywhere inside and how does it matter and that it may be even appropriate to reduce one component namely a drier.

After another 8 weeks, the report of the tests at Chatel-St-Denis (which is where the gasification system was located) was ready and submitted. Dr. Sharan organized a special one-day meeting at Chatel-St-Denis to discuss the results of this test and the implications therefrom for greater commercial deployment in Switzerland. The meeting in Switzerland was attended by PJP, SD and myself. We also visited the lake Lausanne and returned via Geneva which was close to Lausanne.

5.24. Automated gasifier-engine package of Switzerland

After this, a new 100 kg/h system along with a gas engine delivering load into another company was built as per Swiss requirements under a company called Xylowatt located in Lausanne and studies were conducted on the system for efficiency and emissions - gaseous and liquid. All the design of the hardware and system assembly and operations were handled by Pasquale Giordano, the single employee of Xylowatt. The system had full automation and had the ability to inform Gioradano via his mobile if there was any red flag during the operation. Thus, the system met the Swiss standards in terms of operation, performance and emissions. This gave a complete seal to the technology elements of IISc gasification system in Europe. Dr. Dasappa uncovered during one of the visits that Giordano was using a “magic powder” to settle the particulate matter in the effluent filled cooling water tank. This turned out to be a surfactant and comparable surfactant powders were procured in India and tested in the system at the laboratory. This was subsequently implemented in large power generation projects in India. This shows that working with advanced technologies with a inherently new technology will bring other concomitant benefits.

5.25. Inputs from another Canadian visit

Under a Winrock international sponsored visit of a delegation to the Biomass conference of Americas at Montreal, Canada in August 1997, I had visited a 28 MWe steam power generation unit in Vermont, USA and 50 MWe steam power unit in a remote district in Canada both using as-received chipped forest biomass (the possible natural drying that may occur over a few days in large heaps is very little). I specifically argued with the local technical people and they seemed clueless on this subject. Back in India, one 10 MWe steam power plant operator in north Tamilnadu was struggling hard with getting efficiencies when he replaced expensive sun-dry wood with agro-residues like coconut husk which was generally green when it was delivered and its direct use led to power generation drop to 6 MWe and corrosion of many components because of sodium and chlorine related corrosion. They were thinking that using wet biomass inside the combustion system had the same advantages of drying the biomass outside before being introduced into the combustion system! Solutions of wetting the as-received biomass (called retting) and drying it outside to reduce the alkali content of the residue and of course, moisture using waste heat from their furnace for much better conversion and smooth operation were received with distant respect.

Arguments of the kind made above appeared subtle to most practitioners in India, Europe and elsewhere and even academics did not seem to be free of ignoring the perils of not bringing the moisture fraction of biomass fuel to sun-dry conditions before any thermal conversion.

5.26. A German visitor

Sometime during this period, a distinguished visitor from Germany - Mr. Otto Stripp, one of the directors of Bharat-Fritz Werner company visited me after being told about us by Prof. R. Narasimha. His motivation to visit is also somewhat longwinded. Sometime in the early to mid-eighties, Prof. P. D. Grover had created a technology of producing charcoal from biomass pyrolysis and this was popular and many systems were commercially marketed particularly in Tamilnadu, the fuel of importance being coconut shell. Systems started to give problems and MNES got inundated with requests for compensation since the umbrella around which the systems were sold was renewable energy! It appears that one of the affected persons, Mr. Sundaram was known to Mr. Otto Stripp. Otto Stripp had operated charcoal gasifiers in Germany during WWII. Otto Strip thought he could bring in German technology for charcoal generation through us - an academic institution that could get funded, perhaps by both the Governments and help out Mr. Sundaram. He was delightful to talk to as was uncovered by Udups who was also met with by him. Towards the end of the conversation, I indicated that we had new technology on biomass and perhaps what we have done may be exported back to Europe! He was highly displeased and said: What young man, just help out Mr. Sundaram, don't you worry about Germany! I indicated that other matters kept aside, our doors are always open to finding resolution to technical issues and he could approach us. Mr. Stripp had acquired a residence in an isolated bend of the river Cauvery near Srirangapattana about 2 km ahead of Triveni sangama (three-river confluence) and he would stay here in winter months when he visited India. We did visit this place out of curiosity during one of professional gasification related visits to Kerala (Udups, PJP, SD and myself).

5.27. NETPRO - Dr. Sharan's Indian company

Back in India, Dr. Sharan established a company called NETPRO to get formal technology transfer for operations in India. His interest was largely in community improvement activity that could be dealt with using electricity for several productive activities. He built some systems in Araria in Bihar (his home town) and involved some of the other family members for operation of the entire activity. He joined hands with Dr. Ashok Khosla of Development Alternatives and in collaboration with Dr. Arun Kumar, established a power station at Oorcha in Madhya Pradesh that used a biomass feedstock that in local language was called Besharm (shameless) with the botanical name, Ipomoea carnea. This is simply a wild growth along ditches of waste water (as well as fresh water). The word shameless, apparently comes from the fact that the stock that is tubular (like bamboo, for instance) when used as a fuel in traditional stoves produces bad smelling fumes from the central region back into the room. This is in part due to the way fuel is traditionally fed. Long-stock fed into the fire will naturally generate partially burnt or just pyrolyzing fuel in the central region and it fills the hollow region and can easily get out of the back end. If the fuel was cut into much smaller pieces such that both ends can be in the broad region of fire, such a situation would not arise. Thus sometimes, simple issues that could have been resolved otherwise, would become exaggerated as a tradition into blaming the "fuel". This was the reason for assigning this fuel which has a very low density of 175 to 180 kg/m3 was expected to be used in the gasification system. A stock of about 100 kg was sent to IISc for testing in the 5 kg/h gasifier. Since the material was cut into relatively small pieces, it posed no serious problem in operation. Actually, we were delighted that fuel of such density was also being handled. The primary reason is thought to be the near smooth cylindrical geometry of the reactor offering little resistance near the wall.

5.28. Biomass power from gas turbines

In June 1998, MNES called a meeting of all experts to look at what they termed as Advanced biomass gasification. This was essentially high-pressure gasification producing quality gas for being used in gas turbines. This must have originated during the visits of MNES officers to several countries - Sweden and USA in particular because the technology development was in progress in those countries and also visit to MNES by some distinguished scientists and technology providers (whose aim would be to sell the technology) speaking to the Secretary and colleagues and extolling the virtues of the technology. The meeting was attended by a larger number of institutions and amongst others were IICT (Hyderabad), BHEL (Trichy), IIT Madras, IIT Bombay and us. The question posed was: Could Indian scientists put together a package of high-pressure biomass gasifier-based gas turbine for large scale power generation. Based on these discussions led largely by IISc because I had an understanding of both the gas turbines from aerospace side and atmospheric gasification science and technology experience at our laboratory the combination of which was virtually absent in other institutions. Nobody from core gas turbine developing institutions seemed interested as they had their own commitments and this would be a new development with no future demand as they saw. Ultimately, it was decided to be a multi-institutional effort involving IISc (lead institution), BHEL, Trichy responsible for high pressure feed and extraction system, IICT, Hyderabad for an alternate feed system and IIT M (with Prof. Ajit Kumar Kolar of the mechanical department) on associated some fundamental studies. The major dependence for the success of the project was between IISc and BHEL, Trichy and even if the other two institutions performed or did not, it mattered little. If challenged, IISc had the capability to undertake the project on its own, but the hype created that it was a very difficult project and needed multi-institutional participation for success could not be swept away without creating all round annoyance amounting to an allegation that IISc is arrogant, etc. In any case, a similar high-pressure lock-hopper arrangement was designed and the hardware was already in place at BHEL, Trichy on their 6 MWe coal gasification-based power generation project and there would no point in spending time on engineering this hardware for the smaller throughput.

While there was grip on the design and realization of the hardware related to high pressure gasification, the real question was gas turbines. While the true intent of MNES was to build large systems for possible deployment in rich captive bio-waste industries like sugar industry and rice mills, the current demonstration with a small outlay (of about Rs. 6 crores for four institutions) could only address small systems. As different from small vis-a-vis large compression ignition reciprocating engine systems where the compression ratio is about 18 for small systems and 12 to

14 for large systems, the situation is opposite in gas turbines. Small stationary gas turbines have a compressor pressure ratio of 3 to 5 where as large engines have a compressor pressure ratio of up to 20 (aircraft engines needing better performance have compressor pressure ratio up to 40). To get better performance from gas turbines, what is done is to recuperate the energy. The hot exhaust gas at 600°C+ will heat up the compressed air to about 450°C. Thus, the fuel has to add energy by combustion to raise it to about 800°C or so and thus save on the fuel used for producing electrical energy. This approach typically brings up the fuel to electricity efficiency to about 23 - 28% in small systems and 33 - 36% in large systems comparable to what can be obtained by reciprocating engines. There are issues with the development of the high temperature heat exchanger that were inadequately addressed around 1998 to 2000 and hence these systems were being marketed and deployed with care and also denying them to other researchers across the World, lest they uncover the details and make additional progress on material development aspects (perhaps!).

In 1999 - 2000, much effort was made to locate a small gas turbine which could operate with a 75 to 100 kg/h high pressure gasification system (with pressures going up to 5 atms). One Indian agent located a system from Hewlett Packard-Honeywell that was appropriate for our needs. Based on a quotation, we placed an order with them. They indicated that one of our colleagues could visit the gas turbine facility in Florida, USA for special training. Prof. P. J. Paul went along with one of the Indian engineers to Florida for a week for demonstration and training. Beyond this action, there seemed no progress on the delivery of the hardware for the next two months. Letters and communication were exchanged over this time. And there was no response. After much pressure, the Indian agent told us that they had refused to supply the system - reasons were complicated. A Japanese company had taken over this division of HP-Honeywell and they did not want to risk selling us an untested system. Our arguments that we are an R & D institution and are willing to exchange development efforts with who-so-ever they wished to appoint did not cut ice with them. Thus, it became clear then (and perhaps even now) that engagement with overseas technology providers would be fruitless and there was and is no alternative for indigenous gas turbine development efforts. But then, the only organization involved in the development efforts was the gas turbine research and development establishment (GTRE) whose concentration was justifiably on aircraft gas turbines of high performance. BHEL seemed to have received technology transfer on a class of gas turbines, but did not seem to have the intellectual capacity or enthusiasm to develop gas turbines for power generation which are of a different class. Why do I say that these are a different class? Gas turbines generally operate at speeds of 5000 to 10000 because it is only then they can deliver the performance (with smaller systems having to work at higher speeds). These speeds are far away from the those required for power delivery - 1500 to 3000 rpm. Therefore, one would need efficient gear boxes for speed reduction or electrical systems that convert the high frequency power into DC and then use an inverter to get AC 230 V/50 Hz class. If one were operating reciprocating engines, this part was much simpler because the engines operated at around these speeds. In fact, higher power engines operate at lower speeds- the largest power generation systems even as low as 375 rpm.

After much struggle, an UK company that was selling packaged aircraft auxiliary power generation units (APUs) used for lighting and other applications was located. This was an open cycle system compared to the recuperated version discussed earlier. The rise in temperature required in the combustion chamber (of the gas turbine) was from about 75°C to 750°C. This needed a much larger throughput of biomass. The output of the gas turbine power plant was 30 kWe. The rpm of the gas turbine was 8000 and the operating pressure ratio is 3. One would get a net pitiful efficiency of 3 to 5%. There was no choice and so, the system was bought. It arrived at the laboratory and its performance on kerosene was measured and it was consistent with the manual. Having got the system, the design of the entire system was modified around this and over the next several months, the gasifier performance as well as of the engine were optimized. The electrical system was loaded with resistive load the operational performance of the entire system was evaluated. All the partners were involved in the final tests. Though the net performance was poor for practical applications, the learning exercise and the demonstration of the total package were completed as in the proposal.

5.29. Other R & D projects from MNES

Two other projects from MNRE were awarded based on larger concerns that “wood gasifier” is a bad word. The impression is that it would invariably lead to deforestation (climate change was still a fashionable word in international circles). Could we build gasifiers for agricultural residues - in the first instance without much processing. The first route using fluid bed technology was ruled out because

Dr. Vasudevan had shown it would not work. Therefore, a cyclone gasification system was chosen. The pulverized fuel - sawdust available naturally from saw mills and pulverized rice husk were the two extremes studied. Dry sawdust is an energetic fuel and rice husk has always been attractive as a residue available in large quantities and has been explored in several south east Asian countries extensively. The development trials showed that maintaining a fixed fuel rich stoichiometry was a difficult task because the particle size distribution being what it was, it was possible that during a certain period, smaller particles could flow in making the fuel richness higher than nominal. This would lead to greater tar generation. Equally, over other periods, larger particles would flow in leading to fuel leanness and hence lower energy gas would get generated. Fast response valves were obtained and introduced into the system and tests carried out. Measurements were made of the gas quality over different period of time to assess the performance. The net conclusion was that this gas is not engine worthy and the system is good for thermal applications. Since it was necessary to find a solution for light agro-residues, the opposite end of the approach was sought. While these are technical reasons for the poorer performance of gasification of pulverized fuels with cyclone gasifiers, the study during this period revealed many other collateral thought processes for avoiding cyclone gasifiers for anything other than thermal applications.

5.30. The second major biomass project from MNES

It is important to provide the setting for the second major project from MNES.

In the Banff conference that I attended in 1997, I learnt something valuable. Some scientists were developing liquid fuels from Biomass. These required firstly that even solid biomass be dried and pulverised and then subject to a high heating rate of 500 to 1000 K/s temperature to about 450 to 550°C and almost immediately bringing it back to ambient conditions. The reactor residence time therefore would be limited to about 1 to 1.5 s. This would lead to liquids of almost 50% of the solids introduced. If this basic phenomenon was what prevailed in cyclone gasifier even as a fraction, then the observed problems would be explained. Light residues (100 to 300 kg/m3 compared to 500 to 700 kg/m3 for solid biomass) were always seasonal due to the basic character of the agriculture. If one were to build a power station based on agro-residues, one would need to overcome the seasonality issue by sourcing other fuels, a feature that could be complex depending on the location of the power plant. If transportation of fuels from different field sites was considered a needed strategy to the problem of location, transporting low density fuels is expensive - nearly two to three times and depends on fossil fuels. In order to densify the biomass, one would need to preferably use binder-less briquetting technology as a means to aid movement of light residues. If this was accomplished, the same solid fuel gasifier that had worked very well for fire-wood class of fuels might work equally well with light residues with densification. Therefore. the material was briquetted and tests in the classical IISc open top reburn down draft system were conducted. Lo and behold, the performance was outstanding, whether one took briquettes of sawdust, rice husk or mustard stock. These were actually tested for long times. The gas quality was poorer with rice husk briquettes, but the operation was smooth. One would get ash with about 6% carbon compared to 3 to 4% in the case of sawdust.

This became the basis of the second project to bring the technology to as state of readiness to be adopted for power generation using gas engines at industrially relevant power levels - 100 to 500 kWe and for grid synchronizing applications 500 to 1000 kWe and also develop industries for commercial production and operation of the systems using a range of biomass. It was termed the “Strategic Development of Bioenergy” and was sanctioned after it got reviews from a number of distinguished scientists across the country. Admittedly, a tough call, but was taken up without too much of trepidation - because by this time, there were some private consultancy and system design outfits willing to become the intermediaries - bring client industries into discussion to formulate the problem and work out the economics and financial packaging strategies.

One issue that cropped in my mind around that time was if there was a possibility of determining whether a particular large batch of briquettes was good enough to be loaded like sized wood without issues of ash fusion. Based on an earlier work from NREL in which Tom Miles had participated (with whom I was in touch), the presence of potassium and sodium in the biomass was central to resolving the issue. These alkali metal compounds reduced the ash fusion point substantially. Instead of composition analysis, a simple approach invoking the fact that enhanced air supply through the bed will raise the local temperatures leading to possible ash fusion was conceived. A small reverse down-draft gasifier was constructed - a fixed bed of fuel in 100 mm diameter x 100 mm high container with a controlled air supply from the bottom. Both the ash content and the air flow rate at which ash fusion occurred was determined. This led to the determination of the “superficial velocity” - the stream in the empty container which could be taken as the criterion for ash fusion. What this implied finally is that there would a de-rating of the gasifier depending on this parameter. The reverse down-draft system was ultimately developed into oorja stove design whose technology was transferred later to BP, India.

This major project had its share of serious administrative problems for us. While the initiation of the project was done by Dr. K. K. Singh and the first phase of the project went through smoothly, the second year onwards had difficulties at MNES. KKS in his usual over-enthusiasm got the approval and cleared us for the project, some internal administrative issues about the process of getting clearance had got raised. This led to stoppage of fund flow till the issues internally were resolved. After repeated attempts by me to reach various authorities including Dr. R. C. Chopra, senior advisor, MNRE, a committee consisting of Dr. B. C. Jain and Dr. V. V. N. Kishore that came to IISc, examined the activities connected with the project at the laboratory, met with the senior staff of KSCST and cleared the hurdles for financial sanction. This entire period lasted a year. During this period, KSCST maintained the salaries of the project staff and also provided for the minimal expenditure on the experimental studies.

5.31. How many gasifier power packs were built?

During this period and after, more than fifty ambient pressure gasification systems with thirty-five of them for electricity generation have been built. Every year, nearly a hundred people - a farmer to a CEO of a multi-national company would visit the laboratory seeking information, knowledge, cooperative study and some, technology. There was an outstanding team of academics and researchers active in the field at the combustion, gasification and propulsion laboratory in the department dealing with basic research and development, solving field related problems, providing advice on new concepts of bio-residue use in electricity generation process for a rural community or an industry and of course, creating project profiles on techno-economically meaningful basis. The management was later structured to operate under a society called "Advanced Bio-residue Energy Technology Society" (ABETS) whose board chairman would be the director of the Institute in 1999. R & D continued with vigour all along. The total industrial investment was more than 15 million USD equivalent and the royalties received by IISc itself amounted to 0.4 million USD.

5.32. National Biomass Resource Assessment Program (NBRAP)

From 1995 onwards, a program on larger power generation projects from industrial biomass residues like rice husk and co-generation projects for bagasse were launched. The rice husk power generation projects were thrown open to private entrepreneurs with capital subsidy through the state nodal renewable energy agencies. The loans were provided by Indian Renewable Energy Development Agency (IREDA), the commercial arm of the ministry of new and renewable energy (MNRE) and some private banks. This led to a sharp growth in the rice belt of Andhra Pradesh. For about a year and a half, things went very well. Later, the return of loans to the banks and IREDA seemed difficult to realize and it turned out that the 3 to 12 MWe power stations based on rice husk and other waste biomass had difficulty in sourcing the fuel on a sustainable basis at prices originally envisaged. The biomass purchase agreements were not honoured by the suppliers of the residues. Very soon, the projects were turning into non-performing assets (NPAs) as they were called. Meetings were called by the ministry and I was also called in.

On an examination of the data, it showed that the power stations were located too close to each other and the suppliers of biomass fuel were capitalizing on the competition between power plant owners to acquire the fuel to keep their plants running. It was essential for the nodal agencies and MNRE to examine the long-term availability at prices known is advance to ensure bank-ability of the proposals. Being anxious to get the programme to take off with speed, sanctions were issued without adequate scrutiny. This was the central issue. While firefighting the issue was left to a class of officers of the ministry, the question of how to create a good foundation of shared data base to ensure avoidance of such a situation was brought up. Just around this time, the ministry had already sanctioned 500 taluk related projects to consultants to create a data on ground truth surveys on the availability of the bio-residues, their current use and the net that would be available for use in energy related projects. A few reports were already available. These contained information was too sketchy to evaluate. It was suggested that as many reports for a small region be made available for a study to see if information of significance could be extracted. After a study in the next six months, I suggested that the hard documents that they were accustomed to would not add any value for energy consultants to decide on the sustainable availability of the residues for power generation.

I thought over the matter for some period and spoke to a few scientists I knew at ISRO who were earlier at National Remote Sensing Agency (NRSA) under ISRO. Based on this, it appeared possible to develop a collaborative project between ISRO and IISc to develop a national biomass map for agricultural crops. This information could be compared with agricultural ministry generated crop output data and also checked with the ground truth obtained by consultants under the MNRE project. This data would be the basis on which the information of the residue using crop-to-residue ratio and the ways in which the residues were being currently used (with consultant generated information) and obtain the detailed picture of residue available for power generation on a national scale. It took some time to sell these ideas to the ministry. The major effort was related to obtaining space generated maps and manipulating them in various ways. My colleague Dr. N. K. S. Rajan was focused on computer related work and he took the leadership along with a devoted team at the laboratory to deal with these projects. I was involved in being devil's advocate asking searching questions to the team on what was expected from an external view point and also help resolve certain related technical issues. After 3 years when the first version was uploaded, it received a lot of attention from a large number of consultants who helped improve the data base and also new questions for which answers would need to be found from the software. The software was very complex because the data of Kharif and Rabi crops at the level of 5500 taluks was to be converted into searchable information on the map and also provide data tables for suitable downloading.

Many strange aspects were uncovered during this study. The information from the central Government was based on that provided by the state Governments and these data were not accurate and in some circumstances were not communicated to the central Government for reasons related to policies on the procurement price of crops, and other aspects not even clarified to us. I was on the point of writing a code to use the information on rainfall and local sales of fertilizers along with land use data to make a simple prediction of crop and residue output and compare it with the information from other sources to upgrade the quality of the data on a continuous basis. By this time, the project had operated for twelve years and my interests got drawn away into other directions and I left it to the team to move it in the directions they intended.

5.33. Cuba - for Global Environment Facility (GEF) and Uruguay

This short time responsibility arose out of an invitation from Dr. Pradeep Monga who was in United Nations Industrial Development Organization (UNIDO) at that time. He reached out to me to examine the possibility of a GEF project on biomass-based power generation - heat and electricity for Cuba. Dr. Pradeep Monga, IAS officer got his deputation to United Nations Development Program at

New Delhi and later as a senior administrator in UNIDO in Austria. I visited Cuba twice once in 2001 and the second time in 2002. The first visit was exploratory to define the nature and boundaries of the possible projects along with the local team identified for this purpose between the Cuban Government and UNIDO. Meetings were in Havana and an island called Isla de Juvantud. This island had some history. Pirate activity in and around the area left its trace in English literature, notably, Treasure Island by Robert Louis Stevenson a book that I had read from my younger days. The meetings in Havana were conducted in the office of Mr. J. Curbelo who was the local in charge of a possible GEF project. After two-day meetings, we were taken to Isla de Juventud by a ferry for part of the journey. We visited the main power plant and then we were driven to an interior location called Cocodrillo, a village. The entire route went through forest like environment and along the road, we could see thousands of fallen trees of pine (incidentally, an alternate name for this island was Isla de Pinos, island of pines). Apparently, there was tropical storm, somewhat not unusual to the area and that time, it was severe and led to the fall of the trees. It was planned that this village be electrified with a biomass gasification power plant as a demonstration plant. After this visit, the team in Havana created a project proposal that went through several iterations and final discussion took place in Havana in 2002. I went to Havana for this meeting as well. The project size had to be trimmed to a level disliked by the local experts. However, their defence was not strong enough to retain all the segments that they wanted included. Subsequent to these, there were several meetings between UNIDO and Cuba and I did not keep track of them beyond a point.

One outcome of the interactions with Cuba was that one small system of dual fuel based 3.7 kWe operated with a gasifier was put into operation in an year in Cocodrillo (information I could glean from internet sources showed that the system was operating even in 2010: https://www.unido.org/news/biomass-gasification-can-power-grid-areas-cuba). One of the senior operators of the major diesel power plant visited CGPL and spent time understanding the broad principles and operational aspects of biomass gasification technology.

Subsequently, Dr. Monga suggested that we examine the energy scenario in Latin American Countries (LAC) and suggest opportunities for the use of biomass technologies for heat or electricity. This was completed between Prof. S. Dasappa and me over the next year and we submitted a report. This was to be discussed openly. Therefore, he organized a round table discussion with many other experts from the LAC region at CGPL, IISc. Various perspectives were brought out and ideas of how biomass-based technologies made a relevant intervention were also debated. Subsequently, Dr. Monga wanted these to be presented at a conference of UNIDO. This took place in Montevideo, Uruguay from 24 to 27 September 2006. Both Prof. Dasappa and myself flew via Johannesburg (South Africa) and Sao Paulo (Brazil) and then to Montevideo. I uncovered on this flight to Montevideo several other Indians and was surprised. They were all working for Tata Consultancy Service which had a large outfit for information technology work and had a substantial office in Uruguay. I was indeed pleased with this degree of penetration of Indian S & T into countries that I read only in history books in my school days! Most presentations were in Spanish language and we were mute witnesses looking forward to coffee and lunch breaks! The stay for three days in Montevideo where we met Curbelo and other colleagues from Cuba was otherwise a lack-lustre affair.

5.34. The biogas power and H_2S scrubber Technology

Dr. K. K. Singh belonged to an unusual tribe of people who could call spade a spade in very harsh terms sometimes in ways unfavourable to himself. He wanted to be convinced that he was supporting the right cause and once he was convinced, he would not stop at anything to support the cause, sometimes in ways not seen by his colleagues or seniors as proper. In an otherwise polluted environment where every action not consistent with the most rigorous passage of papers was treated as due to some private agenda, unhealthy relations would be imagined and commented upon. He suffered considerably within MNES. Also, on one occasion myself and KKS were on different sides of the table. This was related to H_2S scrubber technology.

A bit of background on our involvement in this technology - It was in 1992-93 that one Mr. Narayanan a consultant to MNES to develop a UNDP project on bio-methanation with the use of the methane rich gas for power generation in large installations visited our laboratory with Mr. Meshram as the MNES officer. We showed him around the laboratory and described to him what we were engaged in. At that time, we were running a thermal gasifier. We had an interesting ejector based premixing arrangement and its combustion in a burner. The flame looked beautiful - really even for us! He got very impressed. He inquired about our abilities to deal with engines operating on biogas. We had already a cumulative experience of several hundred hours on producer gas. Biogas was much easier to work with in terms of engine operation and we described to him that the differences were largely in the carburettor and indicated that resolution demanded a different carburettor hence the issue was straight forward. He then indicated that he would include our group at IISc as one technology institution for providing inputs and advice on engines for large scale bio-methanation projects. We happily agreed to this and the matter was lost track of for more than a year.

Subsequent to the project sanction, MNES formed the National Bioenergy Board for which Secretary MNES was the Chairman. The project director was chosen as Dr. K. K. Singh. He immediately telephoned me and stated that we could not escape him! He held a meeting all the stake holders - technology providers, technology institutions, municipal chiefs and other associated governmental agencies as a kick-off meeting. One industry was Western Paques, a high-profile company. Even though its CEO was invited, a very lower down official attended the meeting and even he acted as though the results of this meeting have very little consequences because they seemed to have their own plans for a commercial initiative on this subject and they would carry through their plans. Many were surprised by this attitude. One of the key elements of the technology was hydrogen sulphide (H_2S) scrubber because all bio-methanation plants with complex feed stock involving human wastes, abattoir wastes, distilleries in sugar plants generate hydrogen sulphide because all healthy natural systems do have a reasonable amount of sulphur that gets converted to hydrogen sulphide in the reactor. The operators of bio-methanation plants indicated that the gas had as high a concentration as 5 to 8% and engines operating on this gas would get wrecked in a few hundred hours of operation since the systems had copper-based components in the rotating machinery and they would degrade with H2S reacting with copper to form cuprous sulphide.

Since the project document did not explicitly include the scrubbers, we indicated that unless the scrubber technology preceded the project implementation, the project implementation had virtually no future. It took considerable persuasion to give an R & D project because the finances in the UNDP project went largely to the scrubber hardware, engine and power handling systems of the individual project of the clients. Both the project and a pilot plant were sanctioned to IISc. As this process was going on, it was important to see how scrubbing could be accomplished. The aim was to develop a technology that used chemicals in a regenerative mode. At that time, we had a colleague named Dr. Jayamurthy who had just finished his Ph. D from the department of Inorganic and physical chemistry department and he was hired to study the methods of cracking the problem. Of course, much of literature was researched and finally, the process was developed using an iron chelating chemical.

After the successful research in 1993, we had some difficulty in looking for partners for the pilot plant. Fortunately, the managing director of M/s KCP Ltd with his distillery attached to a large sugar factory (10000 tonnes/day) at a place called Vuyyuru near Vijayawada agreed to participate in the pilot plant effort with part investment from his side. He appeared very enthusiastic, bordering on being obsessed with new technologies. We felt blessed with this offer. It took several months and many discussions with intermediary officers to get whole thing started up. The plant was operated for six months as a part of commitment to the project. During this period the working team at site was trained.

In the meantime, MNES secretary, Dr. Ashok Parthasarathy took interest in this project, suddenly discovered that this technology must be good and being formerly from NRDC wanted the technology to handed over to NRDC for dissemination to industries in the country. And he called for a meeting with the then NRDC chief, Mr. Sharma, KKS, and myself and suggested that we better get moving soon on this and suggested that Mr. Sharma must visit the laboratory and acquaint himself with the technology. I indicated that I would need to get the permission of the Institute on this because the technology was developed under a grant-in-aid project, and might need additional development depending on the field assessment over a time and that IISc is required to follow DST norms concerning this. When sweeping statements were made by the secretary that he would speak to DST secretary, I indicated that we would abide by whatever became the norm.

After I returned to IISc, spoke to then director, Prof. G. Padmanaban and he assured me that we would follow the written rules no matter what statements were made orally. I was thus caught between KKS who was applying pressure to go along what his secretary had indicated and IISc that indicated somewhat differently. Of course, in the best of interests, the conclusion that PJP, NKSR, SD and myself (the internal council meeting members after the eighties) came to was to have independence of technology transfer and continue with further incremental development, as we had been accustomed to doing in the gasification field (and by this time, five technology transfers to Indian Industries had been effected). The only way of managing the situation was to find “good excuses” for delay to avoid direct confrontation. This is also what happened due to frequent change of secretaries at MNES and promotion of Dr. K K Singh to advisor’s position. Mr. Anil Dhussa became the project director. He did not seem too interested in technology related matters as much as the project. This situation was akin to the famous saying attributed to then Prime minister of India, Sri. P. V. Narasimha Rao who is supposed to have said: Delaying the decision is also a decision.

Sometime during this period, Dr. Jayamurthy left for UK on a post-doctoral fellowship and Mr. Subbukrishna joined the project as a staff of KSCST like in the case of S2 and S3. At this time, Mr. Dhussa became instrumental in getting a project implemented with the cooperation of Central Leather Research Institute (CLRI, a CSIR laboratory). One Dr. Ramanujam of this laboratory was the lead scientist (unfortunately, he died by drowning in the Cauvery river at Trichy sometime in 2019) operating a small waste bio-methanation plant with abattoir waste at a place called Melvisharam close to Vellore in Tamilnadu. The system size was small (25 kWe) capacity and setting up the H2S scrubber was relatively easy. This project also ran for reasonable time for training the appropriate people and got disengaged later. Another major project (250 kWe) that was implemented was in Ugar sugar company in Belgaum district with Mr. Shivagaonkar taking substantial initiative in this project. This underwent various modifications over time.

It is now being handled by NKSR and Subbukrishna is a separate company. This technology has several fluid dynamic aspects related ejector induced enhanced mixing for the ultra-fast liquid phase reactions to occur. Sometime in 2002, being interested in the scrubbing technology, two Indian visitors from the USA and UK commented that they thought this would be a chemical engineering department. On being shown other activities of the laboratory they seemed dumbstruck and stated that while one of them said that he had seen so many laboratories across the World, this is first time he is seeing a laboratory with such wide range of research activities and so many patented products reaching the market.

The period 1990 to 1994 was dotted with several developments on gasification, some made to eliminate what might not work, others to firm up the performance data to enable us to design new systems that would be robust and operate more reliably.

6.1. More difficult than rocket science?

The word “Rocket science” is often used to say something being done is not difficult, generally implying that rocket science is very difficult. Scientists involved in science and engineering of rocket engines like this statement very much as it presents them in dazzling light. But the truth is far from this. While some aspects of rocket science are indeed complex, there are many other fields that are as complex or even more. Consider designing and building a gas turbine engine. People have seen gas turbine engines being started by the commercial pilot hitting the start button for the left side engine and then the right-side engine, taxying to the take-off end of the runway and smoothly taking off (almost every time) and this may be giving an impression that designing and building gas turbine engines is simple and certainly not rocket science!

At this stage, it is appropriate for me to explain the true problems in the design and testing of rocket engines and gas turbine engines. If you consider a solid rocket engine, a lot of apothecary is involved in making the dough out of ammonium perchlorate powder with a liquid fuel, called a pre-polymer. It is so called because the liquid at the initial stages helps making of the dough and subsequently becomes a strong solid due to the formation of bonds between the molecules of the pre-polymer, a process known as polymerization. The solid has both fuel and oxidizer in right proportions and does not need the ambient air for burning and releasing heat. The process of heat release is also chemistry dependent and therefore “propellant engineering” divisions have a large number of chemists and some chemical engineers. On ignition, which is helped by another “propellant like material” the combustion process produces hot products at high pressure of about 50 to 100 atms and high temperature of about 3500 K. The throughput depends on the geometry created for this purpose (for instance star is a typical configuration). The hot gases are designed to flow through a bell-shaped nozzle to produce high velocity at the exit. Higher the velocity, better is the performance.

Liquid rocket engines are complex looking, involve fluid dynamics very much more than the chemistry as in solid rockets. Thus, liquid propellant rocket development divisions have a large number of mechanical engineers with strong aerospace background and very few chemists. The chemists here are largely involved in procuring liquid fuels and oxidizers and depend to a very small extent on solid propellant class of engineering. Plumbing, valves and control systems are all a part of liquid propulsion system.

One might think that solid rockets are simple and liquid rockets are complex. But the fluid flow behaviour has very little mysteries, but solid propellant engineering involving high temperature and high-pressure chemistry could and perhaps can be considered truly mysterious, even now. This is so because one can add 0.25% burn rate modifier like copper chromite or iron oxide and obtain a burn rate change of 25%…truly spectacular and understanding this in completeness is currently beyond the normal effort to help engineer the propellant. Experiments are performed at varying fractions of these “catalysts” and the data plotted against the fraction of the ingredient and the fraction chosen to provide the desired burn rate….more or less.

Yet, Dr. Abdul Kalam always characterized solid rockets as simple and in fact, had an inherent dislike for liquid rockets and I had even joked about it in an open meeting during the ISRO discussion on the choice of liquid propellants for the second stage when he put forward an argument (outside of the committee’s boundary of discussion) that solid propulsion system would simply do the job. This was somewhat unfortunate because he became the director, the organization did not get enough impetus to develop liquid propulsion systems.

If we look at a gas turbine engine, we must realize that it is an air breathing engine that works for several thousand hours - different segments like turbine, combustor, compressors could have life of 3000, 5000 and 10000 hours, if it is for civilian application and an hour or so for an expendable engine and several hundred hours for other military applications. The operation of rocket engines is from a few seconds to a few minutes. The turbine will be cold to begin with, will quickly get heated up in 20 to 40 s. They may reach full power and hence, the highest temperature in another minute or two. During cruise, the temperature may come down a bit and after it lands the engine cools off. Such periodic rise and decay of the temperature will go on for several thousand cycles in the life time of the engine. The turbine blades about 20 to 100 mm long will expand due to rise in temperature. They be rotating at several thousand revolutions per minute and cannot touch the outer cover and cannot contract leaving more spaces for air to bypass flowing over the blades. One needs to choose the right design procedure, material, and machining scheme to make the surfaces very smooth with right assembly, balancing and so on. That building a good gas turbine engine is no ordinary job and that it is much harder than building a rocket engine is something not realized normally.

6.2. Are biomass stoves difficult to design?

Table 6.1 Comparison of parameters for rocket and gas turbine engine and biomass stoves

Parameter	Rocket engine	Gas turbine engine	Biomass stove
Thrust/Power	0.1 to 10^6 kg	10^2 to 10^6 kg	1 to 5 kg/h
Varying thrust/power?	Sometimes	Always	Demanded
Life	A few minutes	Thousand hours	Thousand hours
Repeated use	Mostly no	Always	Always
Fuels	Exotic	Refined kerosene	Firewood, agro-residues
Fuel density	0.07 to 1.7 g/cc	0.8 g/cc	0.1 to 0.8 g/cc
Fuel shape, size	Controlled	-	Widely varying
Prepared fuel cost, Rs/kg	Very high, 500	Not high, 15	Low, 3 to 10
Emissions, CO, NOx, UHC	Not relevant	Very Important	Important, ignored
Investment cost	Very high	High	Low
Users	Experts	Skilled manpower	Unskilled
User friendliness	Unimportant	Unimportant	Very important

Now, we ask a question as to how the specifications on a biomass stove differ from that of a rocket and gas turbine engine? We will look at these in Table 6.1. Such a table may have got prepared for the first time in the literature. This is because very few people in high science and technology have any care for biomass. Just because rocket engines are handled by experts because one uses exotic chemicals that when inadvertently handled lead to explosions or large uncontrolled fires, a general observer thinks that it is very difficult to design. Yes of course, it is difficult to design. But to think that designing a gas turbine engine is simpler is not correct as described in the earlier paragraph and that designing a biomass stove to specifications is simple is very far from truth. What is it that makes it difficult? Whether it is the rocket engine or gas turbine engine, the fuel is chosen to the specifications and the system operated accordingly. When it comes to biomass, even if it is arranged that prepared biomass be supplied, the buyer - a housewife may decide against it stating that she has the fuel and so won't buy. One then needs to strike a barter deal in which good prepared biomass is exchanged for an equivalent magnitude of "her biomass fuel". Such arrangements require corporate like thought processes and are yet not in place anywhere. Therefore, the designer has a narrow pathway for maintaining the performance - emissions first, efficiency next. Curiously, over the last fifty years of the "improved cook stove" program, efficiency was the most dominant parameter for choosing a stove for subsidy program. The MNES program was designed to be technology neutral to prevent bias in favour of a specific group. Unfortunately, this prevented systematic scientific studies that could be subject to discussion. Any further analysis amongst participating agencies/members was neither conceived or benefited from when presented.

It was not and is not recognized that low density thin flakes with a large surface area burn faster without adequate air availability such that the combustion process become very fuel rich - the emissions of unburnt hydrocarbons (UHC) and carbon monoxide (CO) will be very significant. Further, CO cannot be detected by smell and can be inhaled leading to health hazards. It is not that health-related issues were not addressed or studied, but never got connected to combustion technology. So, what is the solution? One needs to make the density range smaller (0.5 to 0.7 g/cc), reduce the variation of shapes and sizes (from 10 to 200 mm to 20 to 40 mm) obviously achieved by sizing firewood like material to smaller ones and light residues pulverized and pelleted so that the fuel bed is a packed bed. Fan based air supply must be in place. The air flow passes through the bed in complex ways; such an arrangement encourages the gasification process - a process that allows the combustion products to further interact with char and generate larger fraction of "clean" fuel rich gases. These can then be burnt with secondary stream of air. Such designs bring down the emissions at least ten-fold, perhaps more. They will not reduce the efficiency, but contribute to its increase. Making heath concerns more important than efficiency is the crucial feature that makes a difference between a good and a bad stove. We must remember that all these need to be achieved with the demand for an acceptable (affordability is not as important under some circumstances) price range for a user who may be unskilled and is unrepentant for use of wood with more moisture than acceptable.

The Oorja alternative or what is technically called reverse downdraft gasification idea (or also known as top lit updraft) was an ideal solution for fixed duration clean heat delivery. Such an idea was pursued and the technology of domestic cooking system that used fan-based air supply operating with two 1.5-volt batteries was transferred to British Petroleum India Energy Ltd (BPEIL) in 2004-2005. Much development took place in collaboration over this period. They actually scaled the production and dissemination activities both stoves and the pelleted agri-fuel in several states in India to over half-a-million households. It was in 2010-2011 when the base costs of agri-fuels like bagasse, groundnut shells became expensive and the final selling price of the pellets became 11 to 12 Rs/kg (as against the affordable 5 Rs/kg in the earlier times), the domestic Oorja disappeared from the market. Attempts to be afloat after BPEIL shut down its operations and transferred the patent rights to an independent company called FEPL formed by the former head of BPEIL, Mr. Mahesh Yagnaraman. They shifted the operations from Bangalore to Pune to optimize the financial outflow. They focused their efforts towards commercial markets in hospitality industry to provide clean combustion systems. This called for systems with much larger throughput of 3 to 6 kg/h instead of 0.8 kg/h for domestic needs. The design was provided through the systematic work of Varun Shivakumar who had chosen to study the Oorja design as a part of his Ph. D. in IISc. During the later part of his work, Mahesh and his colleague Mr. Nilesh Deshpande visited CGPL and got the full details of the design and operation of larger systems. They built these designs and offered them to the hospitality industry. Since it appeared to be a aesthetically sound and an economically viable product, they accepted the system and FEPL increased the production to meet the demands by a large number of clients. This went on for the next three years and FEPL made substantial sums of money during this period, more particularly with the sales of fuel - pellets. Subsequently, the industry wanted a continuous version of the system completely automated if possible. This issue was foreseen by Mr. Mahesh much earlier and wanted me to pursue a solution.

It was in 2014, due to serendipity and the demand from a sand drying industry (from Mr. Sameer Kanabargi of Phoenix Industries, Belgaum) that I uncovered a new behaviour of the combustion system when using secondary air at reasonably high velocities (of about 20 m/s) on a horizontal combustion device (a photograph collage seen in Fig. 19.14. The flame was very clean with very small patches of bright carbon combustion. This was pursued through a systematic study of 1 to 100 kg/h class systems largely at the Jain campus because by this time I was spending more time at Fire and Combustion Research Center at Jain on fire science related problems. It was determined that if we had jet velocities exceeding 10 m/s something that would be obtained from a DC 2 W Sunon blower, we could get clean combustion and water boiling efficiencies of 35 to 39%. This direction of developmental studies aimed at evaluating emissions and minimizing them took a deeper root in the work at Jain. Several variants of the technology were developed for throughputs of 5, 10, 20, 50, 100, 200 kg/h and the geometry and system elements were optimized. Some of these were transferred to FEPL. The variants were termed horizontal continuous clean combustion Device (HC3D), Hybrid ejector induced stove (HERS) and Enhanced ejector induced stove (E-HERS) and vertical ejector-based biomass combustion device (VEBCOD). Several of these technologies are already in the field at this time working on waste wood, briquettes and other fuels including coal. These offer perhaps the cheapest solution to continuous heat generation at high temperatures for a variety of applications. Other applications such as melting aluminium, drying fruits and vegetables, sanitary pad clean thermal disposal are currently under consideration.


NATIONAL TECHNICAL MEET ON BIOMASS GASIFICATION
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PUBLICATIONS - TO WHAT END, PATENTS?

7.1. Why does anybody publish?

The essential idea of publishing comes from the consideration that knowledge should be made known widely both for use and possible further development. Except for specific technologies related family-owned processes for certain medicines or other societal needs and those like alchemy or certain religious rites that are held secret, most other developments are intended to be published and publicised as much as possible. There are of course other considerations that drive people to publish. The reasons may be for the sake of career advancement in the case of faculty in academic institutions or fame after a person has become a full professor. Fame also can bring in rewards and awards. The aspect of awards had actually no limit. One can hanker after it even when one has received large number of awards. That the curriculum vitae will continue to look more and more impressive is the feeling and this becomes the driving force.

During Prof. S. Dhawan's time (1962 - 1981) and during the short tenure of Prof. S. Ramaseshan (1981 - 1984) as the directors, the atmosphere for publishing was more "free" in the sense that the subject of publishing was important but did not override intellectualism; it was essential to be active intellectually - one could do important science inspired development work that might not have "science" centred publications and yet be recognized as a worthwhile faculty member deserving promotion. Slowly, this became less and less and the general attitude of publish or perish became the bottom line. This transition was not simply one factor. Change of the director to Prof. C. N. R. Rao (1984 - 1994) who was a prolific publisher and who used to openly emphasize science and publications and regard several of the faculty in engineering science, with high to moderate respect and some with open disdain. The last aspect created an inevitable hollow feeling amongst several academics in engineering departments and there was an undercurrent of unhealthy remark passing - engineering science faculty commenting that what basic science departments do is to use equipment imported from overseas, continue to obtain data and publish them in relatively short papers whereas it is they who deal largely with physics-based approaches needing long and hard work to get their publications. Engineering department staff also engaged in substantial teaching master courses apart from their Ph. D students where as such a practice had not been installed formally in science departments in the early stages. Science department faculty generally looked down upon engineering departments as an inferior flock with some exceptions. Several such random comments would occasionally be made in cafes to let others overhear! Even so, the ethos of IISc did not get altered much. The deeper roots that faculty had grown in their own academic life could not be altered by these observations. Faculty continued to do what they thought was interesting and useful apart from publications.

7.2. Prof. S. Soundaranayagam and publications

Amongst faculty who published little but were highly regarded was Prof. S. Soundranayagam who was brought in as a Professor by Prof. Dhawan to the department of Mechanical Engineering to pursue the area of turbo-machinery. He had several projects from the turbo-machinery group of GTRE and was on their committees. He had also a continuous stream of consultancy projects from pump designers and manufacturers - particularly in the small hydro-power projects segment. This involved testing for which they had created a facility in the Mechanical engineering department and they carried out advice on modifications for the pumps that were to be certified for use. He was also invited for reviews in large liquid engine projects of ISRO. We had travelled together and were sitting on the review committees, and sometimes promotion committees together. Usually, he spoke briefly and made his observations many more with the eye than with speech. He was very much older than me and I used to make light of the situations in the meetings when we were together - by reading what he was attempting to say. He had read a whole lot of general literature and we would exchange the ideas in the evening walks at VSSC (most usually). Because I had some idea of his area of research during the visit to NASA LaRC in 1987 - 89, I used to try to extract from him what can be considered the juice in the turbo-machinery area and was not greatly successful. Added to this was the fact that there were competitors in the pump testing area - the civil engineering group headed by Prof. Sridharan of the hydraulics stream and on one occasion when I was Chairman, CSIC, I had to deal with two similar projects handled by these two groups with widely varying project costs. After a lengthy discussion at CSIC, I had to finally accept the situation with two different levels of project costs with an unjustifiable observation on the different levels of advice provided to the clients.

Very few of Prof. Soundranayagam's students published or were known for work in turbo-machinery. In fact, they had trying times to get into good positions in academic or other fields. Clearly, not publishing, particularly being in academic field is a truly bad idea.

The question is: how much should one publish? Prof. R. Narasimha had a simple set of suggestions: one should be thinking and being at work all the time on problems of immediate and long-term significance. It should not be too difficult to publish two papers in good journals in a year even with other involvements like in national projects of importance. I do not think Prof. Soundaranayagam belonged to this group. After the retirement of Prof. Soundaranayagam, the department and the Institute were poorer because the area of turbo-machinery, very important for many fields including aircraft gas turbines had and perhaps has no faculty member pursuing the field.

7.3. An unusual personal standpoint

One might ask me as to where I stand with regard to publications. The setting for what I wanted to publish is important. Because of the general environmental influence of Prof. Dhawan's time, publication was intended to be sought only when something significant was uncovered. I did not distinguish between conference and journal publications. This is because it appeared to me that both are important from different perspectives. In a conference when I am presenting an invited or contributed paper, the respect and stature would be directly on the line and it would be important to protect them. The loss of face that might occur in a conference would be much more because the audience might contain many of my friends and colleagues from various institutions who would unhesitatingly give negative marks in case of underperformance. With normal performance, I would get a zero, as I belong to Indian Institute of Science and I must be at least good. There also have been cases, when I have been heard with deep attention and some people actually have complimented me on the clarity of thought and precise communication. In the case of journals, publication in a respected journal would be thought of highly whether it is understood or not and whether the subject would be of true value or not. Papers would need to be read, assimilated, commented upon over a time before a value judgment would get developed. Consequent upon these thoughts, I calibrated things I wrote in papers for a journal or those that I wrote for invited talks or contributed papers for a conference along the same lines - they should be outstanding as far as I am concerned.

My publication list at the time of my promotion from Associate to full professor was considered below acceptable limits and I was not recommended for promotion by the department. The external reviewer reports contained a different highly laudable picture and I received promotion. I was told later by the authorities including the director that the external view of my academic standing seemed so far superior to the internal view, that perhaps, I could also contribute by trying to mend the internal views of my senior colleagues over a time. Of course, in terms of extramural functioning, I had acquired the responsibility of managing the Joint Advanced Technology Program (JATP) with Dr. Abdul Kalam after he became the director of DRDL, Hyderabad and this led to certain internal reach of a different nature. I cannot say I was not at the receiving end of jealousy, but there were so many good friends some inside and many outside the department with whom I always had joyous conversations that helped me lift my spirits apart from periodic excitement when one of my research students uncovered something new in an experiment or a computation.

In this roller-coaster of life of publications and their significance, it is not entirely easy to receive trust-worthy inputs. There may be some who make superficial complimentary statements of the work, others who take an angular view and be unnecessarily critical. Interestingly and fortunately, once, I had visitors in Dr. E. C. Subba Rao who was the head of one of the Tata Research, Design and Development Centre (TRDDC) in Pune and Dr. F. C. Kohli. a distinguished engineer with Tata House, Mumbai to examine if the work on gasification of biomass that we were involved in could be scaled for the benefit of the country. At that time, Dr. Subba Rao stated that he had read the papers I had written with colleagues at IISc in combustion science as well as gasification and found them extremely well written and therefore they were there to discuss possible future possibilities. It is such observations from outside scientists that also help raise the internal spirit. While the discussion was taken to higher levels with my visit to Tata house, the subject did not flower into anything spectacular afterwards.

7.4. Large number of publications?

There are some fields where the publications follow time, annually or biannually! Economics related issues are a classical example. In the field of bioenergy, one classical question that could be asked is what is the cost of the residual agricultural waste that could be bought as a fuel for electricity generation or even upgradation to be further used as domestic or semi-industrial fuel (like pellets or briquettes). This is a function of the land productivity of agricultural outputs (like rice, wheat, groundnut, etc) and therefore the residues. The residues have a prominent use as fodder in the rural setting. Thus, the excess biomass available is what can be deployed as fuel. Since agricultural productivity is a function of many variables (rain, use of fertilizer, extent of land holding, etc), so is the residue availability. This can change on a year-to-year basis. New technology developers would desire some projections of fuel availability over a time for planning. Thus, periodic predictions of the agricultural residue output and their trade become subjects of papers. The net substantive output will only be enhanced number of publications with little of general significance, but these papers enter into counting.

Let us take the example of use of biofuels for cooking. Dr. Kirk R Smith who began his work in the area of environment-energy nexus at the east-west centre in Honolulu and was known to Prof. A. K. N. Reddy and the work we did was sent across to him in the 1986 - 1988 period. Beyond this period, I had no direct contact. I only used to read articles-after-articles in journals with young and upcoming post doctoral fellows from a variety of countries. The substance of most of these papers was simply that classical wood burning or agro-residue burning stoves posed serious health hazard because of the emissions of many complex chemicals like poly-aromatic hydrocarbons. He did not seem to have been interested in determining why this was so and not only that, he was not keen on knowing why this was so. He had great influence on bureaucrats in India and would argue for policy changes. All these seemed reasonable till he began arguing that all cooking appliances must be based on electricity to ensure that emission impact from the poorly burning stoves could be eliminated. That he had to say at an advanced stage in his career seemed surprisingly strange because half the world depended on "poorly burning" stoves and altering the landscape to electric stoves would be just impossible. Further, he did not argue for the fan-based combustion stove that would offer a very good solution to ensure emissions within standards despite the fact that he bought one Oorja stove (of IISc design of 2005) from FEPL, Pune and wrote to Mr. Mahesh Yagnaraman, the CEO of FEPL (First Energy Private Ltd) that the stove functioned very well with the pellet fuel and this could be a good cooking alternative. He wrote 400 hundred papers a substantive number amongst them contain the emissions from based stoves from most countries. If there is a good example of an internationally influential scientist from an outstanding institution like University of California, Berkeley campus being so ineffective as a valuable scientist, I would say Prof. Kirk Smith is….So I conclude that just the number of publications carries little value.

7.5. Number of papers or number of words?

Over years, several other questions came up. Some published a large number of papers with shorter technical content with the number count being very favourable. Others took time to write longer substantive set of publications whose numbers might be fewer, but significance much higher.

Mr. R. N. Narahari was my colleague at CSIC in the administrative cadre who spent a very long time at this centre accumulating considerable experience on consultancy and intellectual property related subjects. He seemed perceptive, observant and critical in assessing the progress around. When I served this centree as its chairman between 1989 to 1991, he became close to me. Subsequently, he intended doing his Ph. D in the area of intellectual property. He studied the "intellectual" life at IISc in terms of perceptions on publications for career advancement and work of significance to society through consultancy and other research projects. Among several questions for which he sought answers in his study, one of them was whether the number of words is correlated to the number of papers that an academic puts down over a fixed period of time. This question came up because, some people would think carefully and write significant and substantial amounts but others put down a large number of incremental findings and the career advancement generally favoured the latter even though quality was and is the acclaimed virtue for the decision-making process.

He obtained the data of more than hundred faculty in the five disciplines, namely, Biological sciences, Chemical sciences, Physical sciences, Electrical sciences and Mechanical sciences, approximately 20 to 25 faculty in each category. He obtained the journals in which they published the papers, made a systematic and laborious work on the size of the papers, the number of words in each page and the equivalent words for figures and tables and then got the number of words per paper and so that for the author. The result of significance was that over 70% of the faculty published between 2 to 7 papers per year, about 20%, 20 to 25 papers and 10% of the faculty 1- 2 papers per year. Amongst the 70% faculty constituting a large majority of the faculty (who are distinguished and have been elected to fellowships of Academies, science and engineering) put down between the extremes of 6000 and 13000 words/ year for 2 papers/year, 3500 to 18000 words/year for 4 papers/year. Two of the faculty whose publication record was in between, received the Fellowship of Royal Society considered prestigious and some far larger than this have not exactly been honoured with the Royal Society Fellowship, but considered outstanding and have received several honours that others within the range have also received. Honour with fellowships apart, the fact that those who publish smaller number of papers with fewer words feel that they are no less than those who publish a whole lot speaks for the fact that intrinsically, faculty do not consider number of papers to be of value, but they pursue that goal religiously! Thus, the number of papers that seems to be the measure of the productivity of faculty is not the only or the appropriate indicator of the performance of faculty.

7.6. A strange experience

Once I received a paper for review from AIAA journal with a written communication from the editor who was a distinguished scientist in his own right indicating that the author of the paper I was to review had not included several of his publications and I should examine if it could be included in my review. I thought this was a low point of seeking reviewer's opinion on the paper. What more, the same editor has had no compunction to ignore the work of several others including ours! I learnt during the evening dinner meetings with scientists from other countries during the international symposia that experience of the kind I had was not exactly new and many from elsewhere had similar experiences.

7.7. Changes over the years

All the changes over a time naturally led to measuring significance of publications that led at later times, to ideas of citation index, H-index of author's publications. It was then stated that scientists tended to cite their own work much more and hence increased citation index is not a very good measure. Later the index modification also got done.

Prof. P. Balaram who was the editor of "Current Science" and also the director of IISc between 2005 to 2012 presented an insightful, illustrative and delightful lecture at a library sciences conference titled "science publication: greed, vanity and the decline of scholarship" in November 2020. He traced the process of publication from 1665 till recently and the changes that have come over this period. The journals have grown in such a way that the private owners have used less than acceptable strategies to lure distinguished scientists as editors of journal so that the academics would rush to get their work into such journals. Journals slowly ask for page charges ostensibly for meeting the expenditure for publishing even though their own expenditures are trivially small. The institutional charges to subscribe to the journals would also be humongous. Fortunately, Alexander Elbakyan of Russia has worked on a software that allows most papers to be opened for private use and hence scholars pursuing research enormously. Of course, established journals feel that this is the violation of copy right and have entered into litigation on this subject in India. In the light of the commercialization of the publication arena, it is unclear what the sanctity of publishing in good journals is.

Unfortunately, we have slowly developed a web of science that is catching us on all wrong fronts.

7.8. Patents?

Patents were somewhat of an afterthought in places like IISc. There was an impression that putting in effort into patenting belonged to a lesser academic order and those who could not publish would engage in patenting.

It was not that patent activity was absent. The first ever documented patent from IISc was filed in the year 1949. There have been IP related activities since then, more as a reactive process. But it had to be forced on the system – one needed to write to the registrar indicating that a piece of work that had been completed – research and development – had resulted in a “process/product” and this needed to get patented. The office of the registrar would send the communication to one of the Assistant/deputy registrars for suitable action. It was more or like a post-office service, the papers would be sent to certain patent attorney in Calcutta (now Kolkata). Any communication from the Attorney, would be sent to the concerned faculty member by the Office for his action and vice versa, and this would go on either till the patent was accepted or otherwise.

In 1995 the responsibility of handling patent related matters was assigned to CSIC. CSIC, then handled the patent activities with a touch of professional approach by getting one its staff members formally trained. Due to enormous pressure from the Government of India (I think), as well the activity grew a separate Intellectual Property Cell (called IP cell) was created in 2004 and IP policy set out in 2005. As a standard procedure, all patent proposals would go through Patent Clearance Committee (PCC). After all this, based on request and feasibility, IP protection was sought within India or PCT (PCT, a Patent Cooperation Treaty application is a *single utility patent filing that gives you international patent-pending status).* By itself, the PCT application does not automatically give you foreign patent rights) request filed through one of the patent attorneys identified by IISc.

But to the best of my knowledge, patenting activity has not owned up institutionally, certainly, say, like a paper in Nature or Science even though the significance and outreach could be much more and the technology of great relevance to India.

The fact that the patent has been awarded would suitably get into the CV of the faculty member concerned and this would be used as one of the contributions to be recognized for promotion of the faculty member. During my tenure, I have rarely heard of any recognition of significance with regard to patents accorded to any faculty member as a worthy accomplishment.

Since I was engaged in work of science-based technology in the biomass area, I was brave enough to generate significant of active and working patents not only in India but overseas as well. Patents on *(a) open top biomass gasification system, (b) its variant involving superior gas cleaning system, (c) a novel scrubber for eliminating sulphur from hydrogen sulphide filled combustible gases like biogas, rich in methane and carbon dioxide, and (d) batch biomass pellet operating combustion system* were obtained with all participating colleagues in India first as law requires. Some of the patents have also got PCT cleared. When the patent on biomass pellet stove was filed in the UK, it got “A” rated clearance. We were told that this is somewhat special and does not happen often.

The Indian patenting process took some 8 to 10 years before the patent was granted. Over a time, due to compliance with WIPO and associated modernization, the normal time has come down and with fast tracked, the time is about an year and a half before the patent processing procedures got completed. A recent enquiry with the patent office revealed that they do not think of this as significant – their argument is that once the patent application is accepted by the office and the document is undergoing processes in the office (whatever they are), they say that the client concerned with the patent need not be worried and can carry on as though the patent is functional. In fact, he can benefit by not having to pay the annual patent maintenance fees!

If I am asked why this patenting was done, it is because the licensees to whom the technology was to be transferred enquired if the technology was patented. If and only if it was patented, the perceived value for any commercial transaction related to upfront technology transfer fees and royalties would be respectable and otherwise, they were not even be interested in the technology.

If the technology was interesting and not expensive to manufacture, many prospective entrepreneurs would be interested in acquiring and practicing the technology. They would not mind paying a relatively small fees for upfront technology transfer and a very small sum on royalty, but this would be so small that the technology would need to be given “free”. If this was done, the institution would receive very little in terms of technology transfer fees. In actuality, the amount collected also turned out to be of small value in comparison to institutional financial strength, but would be counted as an important segment and argued about seriously – and of course, all the time attempting to discount the intellectual strength of the faculty member!

I must recount the steadfastness with which one of our distinguished licensees operated with the patent related issues. Mr. Mahesh Yagnaraman of First energy Private Ltd (earlier as British Petroleum Engineering India Ltd, Bangalore). The technology of pellet based domestic combustion system was found very attractive by a large number of users (amongst four hundred thousand users at one time). This must have been watched over by prospective entrepreneurs wanting to open parallel industries to produce the advanced combustion system by buying up one, stripping it open and trying to find cheaper alternate solutions. A few of them tried and wanted to bring it into the market under different names and make money! It must have taken some time for this information to get to FEPL and when it was obtained, they went into sharp legal actions and shutdown some. In one case, they took on a big industry and they attempted to challenge the patent awarded to IISc – even going beyond their mutual legal fight! At one of these moments, I spent time advising FEPL to moderate its outlook and determine ways by which all these peripheral people can actually become their associates or franchisees in some agreed manner so that they can enhance their visibility and viability. I am not sure I was heard completely.

All these will show that patenting for the sake of enhancing the CV is of one nature. But performing science-based technology development is far more difficult than just practicing science for the sake of science. It is surely more challenging and attractive to some.

But my view after a deep examination of all the issues in academic institutions is that culturally, they have not changed and unless this happens, academic institutions as harbingers of new useful societally relevant technology have a long way to go. I am yet to see a truly distinguished academic with a wholesome attitude towards science and technology includes patent related activities within the institution beyond book keeping and claiming “we also have patents”.

SPECIAL CONSULTANCY PROJECTS

8.1. Flight worthy infrared tow targets

In a general meeting of Defence Research and Development Organization (DRDO) held at the Gas Turbine Research Establishment (GTRE) that I attended in 1982, Group Capt. Krishnan of Aeronautical Development Establishment (ADE) a former student of the department of Aerospace Engineering under the Rockets and Missiles program also attended. During tea, we met and he mentioned to me that they were attempting to procure/build a combustion based infrared tow target to fly at 2 to 3 km altitude and about 2 km behind the aircraft towing the target (in view of safety of the piloted aircraft) to enable tests by missiles and he was in charge of this activity. He enquired if we could provide an indigenous solution to this problem. The target identification sensor was by an infrared device that needed a minimum of radiation. A cylindrical can of about 80 to 90 mm diameter and 100 mm long was expected to be heated to 1200°C and maintained in this condition for about 20 minutes to enable testing a ground-to-air missile. These details were drawn from a quotation of a company in the USA (and the cost apparently was exorbitant). I indicated that if more complete specifications were provided, I would consider the matter. He stated that he would get one of his colleagues by name Venkatesh speak to me on the subject. Subsequently, Mr. Venkatesh and another Flt Lt cadre officer came to IISc and spent some time discussing this issue. I requested Dr. B. N. Raghunandan (he was already faculty member in the department from about 1977) to join in the discussions. They provided the specifications and we indicated that we would make some experiments and get back to them. We configured the test system around a swirl combustion arrangement. The test system consisted of air supply like in flight, a set of air scoops which deliver the air into a combustion chamber in tangential direction and circular tube with inward and side holes of 2 mm diameter to deliver the gaseous LPG fuel was constructed. In the first set up to test the idea, ignition was provided by an open flame. The tangential air flow created a swirling flame with the LPG and a beautiful cylindrical flame at about 80 mm diameter was found both inside and a little outside of the combustion chamber. This seemed like a perfect answer to the requirements of ADE. Once the test was successful, we integrated a spark plug arrangement for electrical ignition. Then we invited them to look at the hardware and its functioning. They were deeply impressed and in fact, overjoyed. It was then that Mr. Venkatesh indicated that they themselves had tried to burn LPG in ADE in somewhat a similar fashion, but ended with a huge flame beyond the duct and they were visibly scared by the size of the flame. The explanation that I provided them was that for the specific application that they projected to us, the only option was to use swirl combustion since what was intended was a cylindrical flame. Use of coaxial air injection if at all conceived, had to to managed very carefully and would not function as well as the swirl combustion system because the flame might be all over or seriously affected by wind direction (angle of attack issues). Thus, the ADE scientists were won over and a consultancy proposal was made and sent across to CSIC. This was discussed in the expert panel of CSIC and cleared for suitable forwarding to ADE. When the project got cleared from ADE end, we indicated to them that we might visit the USA and if needed, we could visit the company that had given a quote to meet with the them and discuss the technical details if of course, the company okayed our visit. The company did agree to receive us and we went to their office in Alabama after the 20th international symposium on combustion at Michigan, Ann Arbor. As could be expected, perhaps, not much came out of this visit.

Over the next year, as committed under the project, we built 6 prototypes and delivered them for possible flight tests. We were told that one test was successful. Beyond that, there was transfer of personnel in ADE and we were not aware of how the other hardware was deployed.

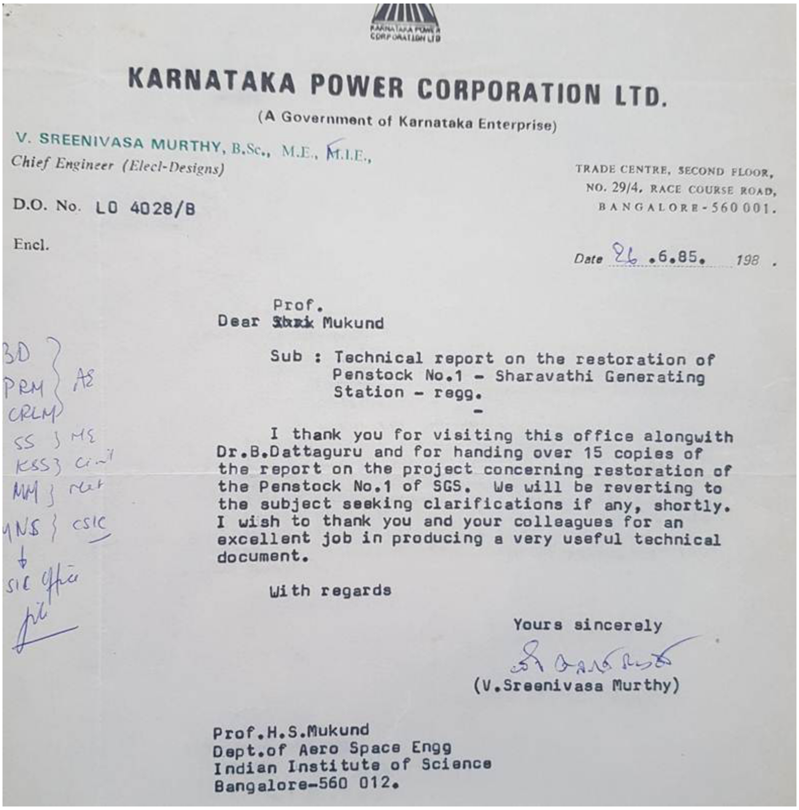
8.2. Penstock affected by landslide at a hydroelectric Power station

In the monsoon of 1984, it was reported that there was a heavy land slide and the penstock pipe of the Sharavathi power station producing a thousand MWe under full discharge conditions had been damaged and therefore, the power output was lower. The power output at that time was also not very high due to reduced demand from agricultural operations and the specific penstock pipe was not operational at the time of the incident. The secretary to the PWD department of the Government of Karnataka (GoK) had close links with several faculty at IISc and he reached out to Prof. M. N. Srinivasan, Chairman, CSIC sometime in October 1984 and enquired if IISc would help out in the restoration of the penstock. He indicated that the people who normally do it are from Pune and they wanted one year and of course an exorbitant level of finances. While the finances were not the principal worry, the fact that they wanted one full year was not acceptable. GoK wanted the penstock to be repaired before the next monsoon and so there were only eight more months to go. Prof. Srinivasan called me and wanted to discuss the issue as to how to go about the subject. This was not unusual because he would be calling me over to CSIC towards the evening for a cup of tea and long conversation on many tricky issues on several occasions. His point was that the reputation of IISc would be at stake if we failed and so he wanted to responsibility to get distributed so that when crisis situation arose he could get inputs from many angles. I had no disagreement with this point of view and we listed the technical areas to be covered first. Weld strength, Structural safety both analysis and testing were one set of issues. Landslide analysis in terms of causes and possible solutions for the prevention was another. Oversight and judgment of critical matters were the other issues. Also, strength of responses was considered central to the consultancy approach. A team of eight people, Prof. B. Dattaguru, Prof. C. R. L. Murthy, Prof. P. R. Mahapatra and myself were from the Aerospace department. Prof. K. S. Subba Rao from civil engineering, Prof. N Mohan Rao from metallurgy, Prof. S. Soundaranayagam and Prof. M. N. Srinivasan from mechanical engineering were to be the consultants. It was suggested that before the proposal was made, could the team visit the power station and take a physical look at the affected penstock. The visit was made and the physical displacement examined. Ten penstock pipes were connected from the reservoir to the power generating station that had the turbines. The penstock was built of large pipes that were welded at several segments. There were reinforced concrete blocks between the lengths. The inclination of the slope was about 30 to 40° around the region where the land slide had hit the penstock and caused a permanent displacement. Structurally stated it appeared like the penstock pipe rigidly held between the concrete blocks had suffered an impulse load from a lateral direction. Externally, there did not appear to be bent, and with no visible cracks. Internal fractures could not be ruled out, however. To some of us, it did not look like a serious problem and the penstock could be restored to normal operation after suitable X ray examination and local repair. Some members were somewhat apprehensive of our strong position and were hesitant on the extent of commitment. Prof. Mahapatra who had a strong background in mechanical engineering even though he developed his capability in guidance systems made some arguments about the nature of possible structural failure and we discussed it separately and concluded that exaggerating the problem had very little value and we should strongly recommend the approach of early repair. We would get the X rays to IISc and have them examined and advise sought if there were questions. This is what we told Prof. Srinivasan and better sense prevailed in the open meeting with the local chief engineer and his team. Subsequently, consultancy proposal was prepared and sent across to Karnataka Power Corporation Limited which was instructed by the Government to go ahead with this proposal. This brought responsibility to some of us more than others in the team. It took several months to get the X-rays done and they were sent across to us to examine. Then, the repair was done and again X rays were taken and these were also examined. In the meantime, in parallel, we did some approximate analysis of the way the penstock had got deformed and examined the structural aspects from multiple viewpoints. Prof. Subba Rao presented his results on soil analysis and the results were not greatly useful in the decision-making process.

Finally, sometime in April 1985, when the system was ready for operations, a three-member team consisting of myself, Prof. C R L Murthy and Prof. Mahapatra made a visit to the site along with acoustic emission equipment. Prof C R L Murthy had specialized in non-destructive testing and had developed expertise in the new approach of acoustic emission. The basis could usually be explained simply with an analogy. If we take a long piece of multi-layered plywood and bend it at the ends, one would get cracking sounds. These are indications of internal structural deformation. These sounds would be much larger if there was a structural failure. Thus, if sensitive acoustic sensors could be put around the problem area and the system loaded, one could expect to obtain electronic signals and put them into a loud speaker one could easily hear the sounds. Of course, calibration would be required and based on extensive work the expert would be able to distinguish the issues in the signal since some random noise could never be ruled out.

This was the final and important event. The equipment was moved up the slope and located around the place where the repair was performed. The acoustic emission equipment would reveal the dynamics of crack growth, if any, due to hydraulic loading. The internal hydraulic loading would be 45 atm inside the 1 m diameter pipe. The experiment was set up for the evening. The valve near the top region (400 m above our location) was opened slowly. We could hear the effects due to this after a while, but the levels were small. After about 30 minutes the entire penstock had attained its full operating pressure and the flow was going through the penstock and there were no events of significance. We waited there for another hour after which we moved the equipment back.

Subsequent to our return we put together a report of all the findings of the project and presented it to KPCL office.



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V. SREENIVASA MURTHY, B.Sc., M.E., M.I.E.,
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Encl.

Date 26.6.85. 198 .

Prof.
Dear ~~Shri~~ Mukund

Sub : Technical report on the restoration of Penstock No.1 - Sharavathi Generating Station - regg.

I thank you for visiting this office alongwith Dr.B.Dattaguru and for handing over 15 copies of the report on the project concerning restoration of the Penstock No.1 of SGS. We will be reverting to the subject seeking clarifications if any, shortly. I wish to thank you and your colleagues for an excellent job in producing a very useful technical document.

With regards

Yours sincerely

(V.Sreenivasa Murthy)

Prof.H.S.Mukund
Dept.of Aero Space Engg
Indian Institute of Science
Bangalore-560 012.

8.3. High velocity burners for stress relieving large storage vessels

Sometime in 1979, my former teacher and my senior colleague later, Prof. G. N. V. Rao sought a meeting between Prof. V. K. Jain and myself. He described to us that he had his cousin who was the managing director of Bharat Heavy Plates and Vessels (BHPV) a public sector undertaking in Vishakapattanam and wanted to speak to us about a “burning” question. We met and he described that they were engaged in building at site locations very large pressure vessels of 10 to 20 m diameter with plate thicknesses of 15 to 30 mm and these vessels constructed by welding together petals pressed at its factory and shipped to the site where the petals were arranged with suitable scaffolding. These pressure vessels needed to be thermally stress relieved according to ASME code and this operation had been outsourced to a company called Cooperheats in the UK. Their engineers came with the burner related equipment and would operate it using LPG storage containers provided at the site. The actual stress relieving operation called for raising the temperature of the entire vessel to around 600°C at a rate not exceeding 20°C/hr and held at this temperature for a duration of a number of hours equal to wall thickness in inches - one-inch-thick plate called for 1 hour of soaking. The most crucial point was that the temperatures over the sphere measured by a large number of thermocouples located at distances no more than 1.5 m between each other should read values no different from each other by 20°C. And these operations are supervised by an inspection agency like Lloyds Register, Bureau Veritas and others. While these aspects themselves were not the problem, The engineers of Cooper-heats performed the operations in such a way that they would shoo away BHPV employees including engineers when they went near the equipment or stroll around the sphere during the operations. He thought this was demeaning and something had to be done about that. He enquired if we could build the burner of the kind they had built and carry out the stress relieving operations. I said we would do that certainly (typical of me, imagining that if a company from UK could do, why couldn't we?). We requested that some pictures and details of the specifications be shared with us by their team. Mr. Ramaraju and Dr. Gururaja of their R & D division approached us with the details of what was called "high velocity burners" used for stress relieving the vessels. Prof. B. N. Raghunandan and myself tried to get some details and they were very sketchy. I went to the library in search of combustion systems with this name. It must be appreciated that “google” search was so far away (more than twenty years away!) that after spending several hours for a few days we figured out a possible approach of using swirl combustion. We built a 100 mm diameter system with tangential air entry with slots from an outer chamber and a circular ring with holes as the gaseous fuel pipe, connected it to a LPG cylinder with a valve to help derive more flow than in a domestic application. There was a suggestion of the use of what was technically called quarl, a convergent-divergent exit section for the 100 mm pipe. After establishing the tangential air flow and some fuel flow, used an external flame to ignite the mixture. After a few adjustments, a nice swirling cylindrical flame was seen inside. Increase of both air flow and the corresponding gaseous fuel flow brought out the flame. We operated the combustion system over a range of conditions and learnt the do’s and don’ts of the operations. A project proposal was made as a consultancy project and it was processed at CSIC by Prof. M. N. Srinivasan and this was sent across to BHPV. After the approval was obtained, we designed the full-scale system. The combustion system with a cylindrical SS duct of 500 mm diameter with a quarl of minimum dimension of 450 mm at the full-scale air flow of 4000 m3/h and fuel flow of 250 kg/h was designed; The air flow had two lines - one for tangential air and another axial coming from the back end. There were butterfly valves on these two lines to enable control the flame shape - with larger amount of axial air, the flame would be longer. These details were sent across to BHPV for the fabrication in their factory.

In the meantime, we uncovered that the team at BHPV had handed out one another project to Dr. B. R. Pai, the combustion head of the propulsion group at National Aeronautical Laboratory with similar aim. Later, BHPV R & D head indicated that he wanted to reduce the risk of investment! Dr. Pai stated in the conversation that he was using ideas of gas turbine to build the combustion system and he knew that the heat transfer to the vessel walls was driven by radiation somewhat nonchalantly as though he knew this all along! I was surprised because this thought had not occurred to me. I had to give him a margin of understanding because he had spent several years in the UK at the imperial college of London which is where he did his Ph. D. I came back, made simple radiation calculations and found that if I took the emissivity as unity which is about right for this large size vessel, and temperature as the flame temperature of about 1500 K, the temperature rise rate of the sphere would be about 1000 K/ hr! The only way radiation flux would match the practically observed value would be when we took the gas temperature to be 900 K, just about 30 to 50 K above the expected wall temperature. This caused in me deep concern and I was determined to get to the bottom particularly when I found that Dr. Pai was perhaps wrong! Little was it known at that time how the solution would unravel till the experiments and computational study were performed by Mr. N. K. S. Rajan for his Ph. D.

Keeping this matter aside, we had to prepare to go to Vishakapattanam for experimental demonstration of ideas to the team. BNR and myself spent two days for this event. When we were demonstrating the burner, I was explaining that the nature of the flame will change if we changed the axial air fraction. But nothing happened to the shape of the flame…puzzling it was…the reputation of two distinguished scientists from IISc was at stake. After an examination of the system, it was uncovered that the valve control shaft was disconnected from the butterfly arrangement inside! Once corrected, the flame behaved as “claimed” and the reputation got restored!!

Our major “test” was to clear the actual stress relieving operation in the presence of third-party inspectors. The first project on which the British technology was replaced by Indian technology was at Mathura refineries in March 1981. Both BNR and myself reached their guest house in New Delhi, had lunch and proceeded to Mathura. We were accommodated in a guest house and we reached the site the next day. Many activities were in progress including the fitment of the burner towards the bottom of the spherical vessel which was insulated with mineral wool and some sixty thermocouples were connected to two recorders in a shed just around the vessel. We examined all the equipment and it would be incorrect to say that we were confident. There was a momentum in the environment which pushed us to the front and this buoyancy kept us moving. We finished lunch and were back for the start of the stress relieving action. They did the puja at about 3.30 pm, we all took the aarti and the blower was turned on and suddenly there was a flash indicating short circuit and puzzled look on the faces. Electrical cable connections were addressed and the blower was restarted. Ignition was turned on and LPG was let in. The flame caught on inside as a low rumble showed. It took another two hours before the temperatures were beginning to depart from the ambient values. Towards the evening, BNR and Dr. Gururaja left for dinner and indicated that they would return by sometime during the night to take over the operations from me and Mr. Ramaraju. 8 pm passed by and 9 pm arrived, and our friends did not arrive, yet. We then got the information that there was an accident on the road, the vehicle carrying our friends had overturned and all the occupants were injured to small or larger extent and some hospitalized. We were told to carry on with the stress relieving operation and BNR might arrive the next day morning. The temperature kept creeping up and reached around 400°C by the morning. Between Mr. Ramaraju and myself, we finished the morning ablutions and continued watching over the rise in temperature. BNR arrived towards noon and indicated that because of the accident when the vehicle tumbled over, he had hit against the vehicle interiors and got hurt internally and actually could not sleep well at all. He seemed to be in a condition when he could sit in front of the data recorders and both myself and Mr. Ramaraju left for the guest house to take some rest. I could not sleep well also and returned by about 5 pm. Mr Ramaraju had not woken up by then and so I came away to the site. The temperature had climbed to near 600°C, with some at 575°C and others at 630°C. We tried to loosen the insulation when the temperature was reading 630°C and tighten the insulation when the temperature was lower than 600°C. This seemed to work in bringing the temperature closer to 600°C. We then learnt that the British guys were also asking the technicians to do similar things. We were not quite concerned about the actual temperature distribution, but how the inspector of Bureau Veritas would react. This was because, the thermal conduction process along the wall would have occurred to homogenize the temperatures, but varying local heat losses near the thermocouple joints could lead to differing values.

By attempting to loosen or tighten the insulation around the thermocouples, the recorded temperatures would get altered. Both BNR and myself were working with the staff who would go to the specific point on the sphere and alter the local environment. The temperatures reached 600 ± 20°C around 10 pm about 30 hours after the start of the operation. The soaking period was considered crucial and all the senior people were around as also the inspector. The soaking ended by about 11.30 pm and the burner was switched off. The cooling rate would also be low and we waited there till about 2.00 am. We left the site and took our bags and went to the railway station to catch the 2.30 am train to New Delhi. We went from the railway station to their guest house, washed up, had breakfast and went to the airport. We had an open return ticket and got on to the flight and returned to Bangalore by noon. We slept on the flight. After returning home and having had some food, again slept for another 18 hours (till next day morning!). We had the satisfaction completing the contemplated action to the satisfaction of all concerned.

While the consultancy project with BHPV ended on this successful note, the success story did not end with this. The issue of the heating rate was a subject that was bothering me and I suggested that Mr. N. K. S. Rajan (NKSR) who had not yet registered for a degree to pick up this problem and begin a study. Since I also wanted a computational study to be conducted and I wanted some advanced approach to be used for the computational study, I wanted Prof. Paul also to be a supervisor for his thesis. It was also important to have Prof. V. K. Jain as a formal supervisor to have a certain administrative comfort for progressing the research as NKSR was still on the project whose principal investigator was Prof. V. K. Jain. We figured out that we could get the most crucial inputs if we carried out a fluid dynamic study in water. For instance, we could use hot water at around 90°C and start with cold water inside a sphere and examine the flow and temperature distribution. This was done soon enough and we found that the hot jet was going up straight till the top and a large part would recirculate. A close examination of the flow at the bottom region showed that the cold water was entrained by the higher velocity hot jet and the jet would cool off to a mean value that would keep rising with time. The entrainment process would cause a recirculation zone in all the regions outside of the core jet. We further confirmed this by introducing a coloured fluid with hot water and seeing its path. Also, in any recirculation zone the velocities would be small and could also be reverse direction. While these deductions appeared insightful and novel at that time, they would seem very natural after some "cool" thinking if I had done!

In the meantime, CSIC received a request for stress relieving technology from M/s Cauvery Engineering services, Trichy (Tiruchirapally) sometime later (in 1984-1985). By this time, BNR had left on a sabbatical to Prof. S. Okajima's laboratory in Japan. We invited them to come to Bangalore and Prof. M. N. Srinivasan arranged a meeting at our guest house. Only I could attend the meeting. I indicated to the team from Cauvery engineering (Mr. Kalidas and Ramkumar) that we needed to do something new for them in terms of high velocity burner as I consider it on the border line of infringement of proprietary nature of the consultancy project with BHPV. I stated that we could give them kerosene based high velocity burners and the stress relieving operation was only one of training the personnel as to how to conduct the operation and there was nothing original from our side. This was finally agreed to and contractual arrangements were signed up later. A little while later, CSIC received a formal letter from BHPV objecting to the project with M/s Cauvery engineering stating that we are violating the consultancy agreement. Though this argument by BHPV was not a strong argument, we wanted to state the truth and win them over. We indicated that the specific project contemplated was with kerosene fuel and therefore was not overlapping the development that IISc did for BHPV. The matter got closed at that stage. The next stage of the consultancy proposal had me and Prof. P. J. Paul as the consultants as I had shifted my office from the main building to CGPL in search of more intense pursuit of the scientific activities and I wished to reduce the dependence on other seniors since I was also Professor by that time.

We provided the design of kerosene combustion system to them and the system was built and we tried it out at their works in Trichy. Their projects for building large vessels and stress relieving them came up in Rourkela (Orissa), Kalyani (West Bengal) and Cochin (Kerala). We involved Dr. N. K. S Rajan in these projects so that he could observe the stress relieving process to get a better appreciation of the system beyond the actual responsibility for stress relieving satisfactorily. In each of these places we had to stay for 3 days to complete the stress relieving operation amidst the local logistical issues. Mr. N. Sukumar was the field person who was indeed smart and was able to deal with technical and local issues with a smiling face. Mr. Janakiraman was his assistant in the operations.

As a part of the research effort two medium scale experiments were performed one at Trichy and another at CGPL. We used a 2 m size sphere at Trichy and 1.5 m sphere at CGPL and conducted the heating test with insulation and select temperatures on the surface of the sphere and also the temperature of gases inside the sphere using a very long thermocouple. These showed that the temperature differences between the wall and the gas were small ~ 30°C. To understand the processes involved computational studies were conducted on the flow and heat transfer processes inside the sphere. The computations were very revealing. Free convection had to be included in the calculations to determine the reverse flow structure that matched well with experimental results and showed that internal mixing characteristics were responsible for the internal temperature distribution not vastly different from that at the wall. Heat transfer by radiation had not much to do with the rate of heat transfer to the wall. This shows how mistaken a superficial deduction about the fluid flow processes could be. This in fact closed the chapter on the stress relieving activities and connecting them to the science of stress relieving.

SCIENCE AND TECHNOLOGY EXCHANGE

9.1. Australia and New Zealand

A tour of four Indian officials noted above was sponsored by MNES, Government of India to visit Australia and New Zealand and study several facilities - high-rate bio-methanation and waste-to-energy technologies to obtain a first-hand appreciation to the technologies and their economics currently prevalent in Australia and New Zealand, and also examine the possibilities of tie up for technology transfer in December 2000. The four-member team consisted of two IAS officers belonging to the municipal corporations in Mumbai and Chennai, the finance officer from MNRE and myself. Some aspects of the visit related to policy issues in relationship to those practised in India and the possibility of collaboration/reverse technology transfer were not on the mind, but not ruled out, particularly because there could be technologies from India which could be more economically supplied and serviced. The prominent cities visited were Perth in Western Australia, Brisbane, Sydney and Canberra in Eastern Australia and Auckland in New Zealand.

The visit contained exploration of three land fill sites including power generation (two in Perth area and one in Brisbane), three sewage treatment plants (two in Perth area and one in New Zealand), one gasification plant for wastes (discussions and manufacturing site in Brisbane and actual facility at Wollongong near Sydney), one small scale gasification technology related discussions in New Zealand, policy discussions in Perth and Australian Green House gas office at Canberra, Management of wastes and project conceptualization in Perth, Pollution remediation and control measures in Perth, other related places like coal seam methane based power generation facility, visits to native tribal areas near Perth. It must be brought out that both at Perth and in Eastern Australia, the visits were extremely well coordinated by CASE (Mr. Kim Trouchet) and EDL, India Ltd (Mr. Sunand Sharma).

The single most important distinguishing feature was that all the plants were extremely well instrumented for monitoring and control to the extent possible or relevant and work 24 hours a day. The next most important feature at the sewage treatment plant (STP) in Perth area was that both bio-methanation and sewage liquid-to-solid particles - liquid fuel were being carried out.

The urban solid waste management approach currently prevalent in these countries was undergoing change. While those which were operating then were those which were established twenty years ago, there was a move to close the landfills in a few years from now due largely to the problem of leachates and other long period environmental problems. The best strategy for the large cities would be to adopt reduction in size as much as possible and the principal way this would be achieved was combustion since ash (that is less than 10% dry input material) was the only one needing disposal. In this sense, the technology at EDL would be interesting. Though the technology demonstration to the visiting Indian group was not complete (power generation was not demonstrated), it would be valuable to have the technology in Chennai or any other place.

During the stay in Perth we visited a native tribal area near Perth.

9.2. Perth

On the 10th April 2000, we were received by Mr. Kim Trouchet (of CASE) at the hotel - Emerald Hotel - the hotel we stayed - and after introduction, had a meeting with Mr. Dennis Smedley of the regulatory body of the Office of Energy in the first meeting for the day. Two major policy drivers for renewable energy in Western Australia were the national aim of achieving an incremental 2% of the total energy from renewables in the next five years, which imply wind and biomass, and another agenda of green power in which specific financial facilitation is provided to power projects in isolated regions.

One of the major wood-to-energy projects contemplated was a 1 MWe project related to Mallee plantation (a kind of Eucalyptus which grows in desert like environments shooting the roots to deep into the soil and drawing the water from the highly saline "old" water) called integrated wood project (IWP). In this project, it was aimed to obtain multiple outputs - oil from the leaves, gasification of the resultant leaves and pyrolysis of wood to generate gases for electricity generation and activating the char to generate activated carbon, the entire process leading to more employment generation and stabilizing the environment. The project needed an investment of 5 million Au dollars at 1 MWe. In fact, the estimates for a project of a comparable nature with coconut shell to energy and charcoal at 1 MWe power using IISc open top reburn gasifier and gas engine - generator set indicate a magnitude of 2.5 million Au dollars per MWe, typically half the investment cost envisaged by the Australian team. Much discussion followed this presentation and ideas of the same kind with Juliflora prosopis were thought viable in some parts of India.

9.3. Waste water facility and urban solid waste

In the afternoon, a visit to waste water handling facility of Perth was arranged. This facility handled the sewage of little more than a third of the city of Perth (more specifically, the three hundred thousand of the inhabitants were estimated to generate on the mean 200 litres per head per day amounting to 60 million litres per day equivalent waste water with 0.02 to 0.03% solids). This facility produced 15 tonne dry sludge every day. The interesting point of the entire process was that the liquid was centrifuged to concentrate the solids content to 28% and then the material made in a pug mill into pellets of 2 to 4 mm diameter which were flash dried in a roaster in which the heat for drying was obtained from fluidized bed combustion of the material (with natural gas start up) to obtain pellets of 5% moisture content. In another new process developed by the team somewhat uniquely, the pellets were flash pyrolyzed to lead to liquid fuels (30% approximately) with a calorific value of 35 MJ/kg. The char in the system was used as a tar cracker and the final material burnt in the fluid bed combustor for drying the pellets.

The entire process was carefully thought out and appeared at first sight to be thermodynamically efficient. Of course, the economy of the process did not appear sound. No numbers on costs were provided, possibly because no such estimates existed and on questioning the possible prohibitive costs involved, the point was not objected to and it was tacitly understood to be not economical. On the whole this segment of the visit was technically extraordinary and worthwhile.

The waste management strategy was to have a weekly collection system for in-vessel composting of some green waste, fortnightly collections for materials recovery purposes, tri-annual collections for green waste for mulching purposes, annual collections, again for recyclables. Typical population size was 340,000 with 12000 households (the average house size was about 3). The total waste handled was 130,000 tonnes a year - 330 tonnes a day (small compared to Chennai or Mumbai). The investment cost in the technology including civil works is 35 million Au dollar with the materials recovery facility of 3 to 5 million Au dollar being contracted out for investment with an assured purchase rate of 70 Au dollar/tonne of the recovered material and the rest being built and owned by themselves. The interesting part of the compost facility was that most of it was under negative pressure to ensure non-emission of foul gases. The final stream of the air passed through a bed of biofilter consisting of about a meter and a half deep wood chip bed and it appears the air is completely cleaned on passage through this. The compost was likely to be sold at 10 to 20 Au dollar per tonne though in times its sale price may go up to 40 Au dollars per tonne.

On an enquiry as to why they had gone into aerobic treatment (composting) and why they could not do an anaerobic treatment leading to the generation of biogas with consequent energy recovery, their answer was that the adequacy of electricity did not make it imperative for them to go in for anaerobic treatment. The fact that mulching helped stabilize the soil which was otherwise poor was important even though volume reduction called for gasification/incineration as the more effective routes. This perspective was truly interesting.

9.3. Brisbane

We flew into Brisbane on 13th April 2000 and were received by Mr. Sunand Sharma and Sabharwal of EDL, India Limited. We met some members of the team at dinner the same day - Paul Woolfan, group manager, technical, Albert Smith III, general a manger - legal and finance, Rick Ralph, Recycling systems manager, Tony Whiteman, technical development manager, David Neuwen, product development manager, all of Bright Star International. We met Paul Whiteman, the CEO of Bright Star International and Executive Director of Energy Developments Ltd and Mr. W. L. Lazarus, general manager - Australia operations. Mr. Paul Whitemen appeared very energetic, well informed and authentic throughout the contact period. He seemed to have a varied career from chores on a ship to technical activities on a ship to engineering.

9.4. Urban solid waste handling facility

On the morning of 14th April 2000, we were shown a video of the operations related to waste processing and preparation facility dismantled a few days earlier. the as-received material went through an autoclave run at 5 bars and 130°C for 40 mins and downloading took another 20 mins. Plastics, glass and steel went through the autoclave for reasons which were undefendable. Constituting 30% of the material received, the energy going to heating and cooling was by no means insignificant. On questioning, they indicated awareness, but seemed to think it as a small issue. The material was then passed through eddy current magnetic separators for steel, and after removal of glass and other inorganic stuff is passed through a shredder (hammer mill in the current system, but would be changed in later systems), apparently, autoclaving was thought to cause some activation for further process to be facilitated. Regarding the size of material acceptable to the reformation process, it was indicated as a maximum of 10 mm all around. Regarding the moisture content acceptable, it was brought out to be at 35 to 50%. The upper limit was set to be about 60%. After this, we were shown the power pack. The 40-foot container had the highly packaged set of elements - engine with a modified oil bath which could be used for transfer into the engine section, a separate waste oil bath all connected with pumps so that automatic transfers could be effected. There was a roots blower to draw the gas from a landfill through a relatively small moisture trap and deliver it to the engine through a pressure regulator which maintained the downstream pressure at 300 mm water gauge. Downstream of the turbo-superchargers, there was a total flow regulating valve.

There was an engine management system which monitored all the cylinder temperatures typically varying between 230 to 430°C depending on the load. Beyond about 50% load, the temperature seemed to saturate at 385°C. Some optimization of ignition timing was needed for landfill gas operations. The data were being accumulated and arranged for control system design. Apparently, it was a critical input and operational performance was affected by it. That is why the automatic management system was deployed so that looking at the peak pressure data averaged over all the cylinders and over some cycles, ignition delay could be set electronically. The system design was outstanding and emission standards were met well. We were shown the computer management system of one of their plants in UK being accessed from their office in Brisbane. After accessing the system through password protection, the system parameters were displayed. It was also pointed out that remote operations like oil change and waste oil pump management could be effected through remote control.

This engineering marvel appeared very impressive, but was extremely common in many high technology applications. After this segment, we were shown the manufacturing facilities for the gasifier. Again, of modular construction, with several components being obtained from subcontractors, assembly and packaging were being performed during our visit. There were further discussions after the visit. In a presentation on the background of the company, it was brought out that EDL established in 1988 with three partners - Paul Whiteman, W Lancart, and Walter Pahor was involved in remote area power generation both from gas turbines as well as reciprocating engines using landfill gas and coal seam methane gas. They had built a total of over 100 MWe at more than six sites. They were quoted on the Australian Stock Exchange from 1993. Overseas expansion into USA, Greece, and England took place between 1996 and 1998. In so far as the new technology on biogas was concerned, they had formed a new company called Brightstar International along with Brightstar Synfuel Corporation, USA with 88% shares being held by EDL and 12% by Brightstar Corporation Limited (1995).

The discussions then went on to a technical description of the new plant being conceived. The incoming urban waste including glass and metal was processed through autoclave at 5 bars and 130°C. Their assessment was that about 30% of their waste consisted of metal and glass. It was pointed out that the energy expenditure in simply heating and cooling of this material appeared wasteful. The response did not appear satisfactory and in any case, if, in the Indian context, segregation was taken up, this part could be understood to be taken care. The material would then be shredded preparing it for the gasification process. The gasification process consisted of high temperature pyrolysis with the necessary residence time. The temperature was set at 930°C+ and residence time about 1 to 1.5 s in this temperature range. The material was screw pressed to build a pressurized segment at 10 bars into which producer gas at this pressure was injected for material transportation. The material was heated to 700°C in two heat exchangers and then it passed through a high Nickel steel tube 100 mm diameter set out in a coiled coil form in a furnace maintained at 1300 to 1400°C so that with radiant heat transfer, the duct was a maintained at 930°C+.

They did not explain many aspects directly. It was brought out through a long series of discussions on that day as well as during the visit to Whites Gully green waste facility at various times. The question that was bothering me in particular was whether it was gasification or pyrolysis. The two were seen being used in a concomitant way and this was definitely not correct. It became clear after it was stated that the regime of operation was high temperature pyrolysis and the output gas stream was unaffected chemically by the presence of moisture content in the biomass. Of course, the thermal balance would be better with dried biomass and to this extent absence of moisture would be beneficial. To the question as how there was a variation in the gas composition indicated in their documents, it was brought out that this was due to operating temperature variation. that is - if the temperature varied by 20 to 30°C over this range, there would be compositional variations as well. In the early development phase, the gas composition showed higher amount of hydrogen even as high as 60%. The detonation problems in the engine called for limiting the hydrogen content to less than 30% or so. The change in operating parameters - pressure and temperature were related to this.

All the technology elements were developed by them with little outside input; in point of fact, their experience had been that any support from universities, like the Queensland University, had been on the periphery and all core developments had needed intense and focused activity by their team. I asked at one point of time if they had done any modelling studies on the performance of the system have been made. It was brought out that the problem was too complex and no such study has been made. They thought that it was perhaps infructuous to do such studies. They also indicated that the gas composition was about the same no matter whether they used sawdust, urban waste or pig waste or chicken waste. The char which was generated is graphitised in part and some fine dust is activated carbon. They did not seem to have explored the magnitude of the different kinds of carbon. We actually were shown the char. It looked like what they had described. After the reactor, the gas was taken to a high efficiency cyclone with a pressure drop of 20 kPa and this was the one which extracted through an auger into the lock hopper system for char extraction. The gas was then taken through a venturi scrubber with a pressure drop of 20 kPa and this ensured dust and part tar removal. Further tar removal occurred through a tube in tube heat exchanger with fins on the outer part of the inner tube. Water which is at the normal temperature in the first two passes and chilled to 0C in the next two passes was used as the solution to the tar extraction problem. These ducts were 65 mm id with fins on the outer surface and 127 mm outer tube diameter and 2 m long with headers at both top and bottom. There were four passes for water recirculation. There were two banks for tar clean up. Only one bank would be used at a time. The periodicity of change over from one bank to the other is 1 hr!. The change from one bank to the other was done based on the pressure drop across the gas line. This could be expected to go up after tar has packed into the annular space.

The way tar was extracted from the used one to prepare it for operation after an hour was by using hot water. This apparently removed the tar sticking to the fins more particularly. This appeared surprising, but I did not express it. The reason was that tar is so difficult to deal with that even some organic solvents did not dissolve them that as to how just hot water could deal with the tar was totally unclear. I intended to see the tar itself, but could not because they did show the tar drum. However, he had occasion to look at the water in a container supposedly from the clarifier which was a part of the tar clean up system. I dipped my fingers into the water much to the astonishment of Mr. Neuman who was showing us around and found that the ammoniacal content was high. The pressure drop on the cooling/cleaning circuit is also large - 20 kPa and thereabouts. The point is that because their operating pressures are high, they can afford to apportion reasonable amounts of pressure losses to these segments to assist the gas clean up. It was therefore possible to accept the levels of cleanliness of the gas that they claimed - 1 ppm of tar. There was a gas chromatograph for the measurement of the gas composition. On an enquiry regarding the methodology for calibration, more particularly the possibility of the use of a standard mixture, there was an immediate agreement, but the actual cylinder with standard mixture seemed not to be around. The gas engine was not running at the time of the visit. The gasifier itself was functioning at 300 kg/hr of the biofeed stock much lower than is required for nominal power of the system. The total system including the enginegenset not functioning caused some disappointment particularly when great deal of focus is on Whites Gully facility.

9.5. Landfill site

In the afternoon we visited their landfill site at Lucas Heights, the landfill gas power station. Again this power station is running completely devoid of manpower with an periodic monitoring through computers connected to the instrumentation required to monitor the performance. Only when there was a problem of serious nature would it call for the intervention for which somebody identified locally might be deployed. The gas extraction, scrubbing and mist elimination, roots blower, piping to take the gas to the Caterpiller engine were about the same as in the other landfill power stations. Also, the instrumentation, computerized data acquisition and access through modem for long distance monitoring and control were similar.

On the evening of 15th April, after the visit to the landfill site we were hosted a dinner by the CEO, Mr. Paul Whiteman. Several of the colleagues were present at this dinner meeting. I pursued with Mr. Whiteman several points concerning the choice of reciprocating engines vis-a-vis the gas turbine engines which promised much longer maintenance free operation. He gave me a long background of their experiences with M/s Solar turbines who were intended to be commissioned to develop the syngas-based gas turbine. He gave me technical reasons of flame speeds being large for hydrogen rich mixture causing difficulties of hot spots in local zones despite my drawing attention to him that in a diffusion flame idea for premixed combustion were not relevant. I politely dropped the issue after a while.

He also brought out the issues of spare part availability and costs which led them to move away from Caterpiller to Deutz with whom they seemed to be happy.

9.6. Sydney

The next day, the 16th April 2000 (Sunday) we moved to Sydney. Afternoon was spent in the Sydney harbour cruise. The following day was the visit to Appin Power station based on Coal seam methane gas and then to Whites Gulley green waste power station.

9.7. Appin power station - coal seam methane based

The Appin power station was an impressive facility. The difference between coal bed methane and coal seam methane is that in the latter, coal extraction is accompanied by the extraction of the gas. In the former case, though, the purpose is only gas extraction. We were provided a number of details of the coal seam structure, the manner of mining, the method of tapping the gases, their scrubbing before being taken to the engines. There were 54 engines of 1 MWe each, all being put together into a single grid paralleled arrangement. That 54 MWe generation system configuration should consist of 54 systems caused in me apprehension about the conceptualization. We were told that their analysis - technical and financial indicated amongst combined cycle gas turbine, steam turbine and reciprocating engine option, the choice they had made was the most appropriate. I indicated interest in looking at comparative statements if they could provide them. They monitor the performance of all the systems through a computer extensively. The instrumentation used was also extensive. This was done for the gas composition and all the appropriate parameters of the engine system.

9.8. Canberra

On 18th April 2000, we went to Canberra to visit the Office of Green House Gas of the department of Environment and heritage. The office headed by a chief executive and with five different activities - emissions trading, green house policy group, sustainable energy group, partnership group and corporate communications group and other infrastructure group with a total of 180 staff. Their role was to manage GHG abatement program of 400 million Au dollars, 60 million Au dollars for renewable energy projects and a 10 million Au dollars showcase program. The meeting was conducted by Mr. Colin Grant, Deputy CEO and several colleagues heading the various groups and attended by the Indian team, Mr. Sharma and Sabharwal of EDL India and Cavin Grant of EDL technologies, Australia. The overview of the activities was provided by Mr. Grant. He described various activities of the groups noted above. He indicated that they were administratively handled by the ministry of environment and heritage even though they were responsible for the three ministers - Environment and heritage, Industry, Science and resources, Agriculture, fisheries and forestry and five other junior ministers of departments. They seemed very enthusiastic in their effort to implement the plan. The most important action they were involved in was to get through legislation on the enhancement of contribution of 2% of the total energy in Australia this amounting to 9500 GWh from renewables by 2010. This program has got substantially distorted over time.

9.9. New Zealand

Doug Williams, gasification enthusiast-scientist

We arrived at Auckland towards the evening of 19th April 2000. The visits in New Zealand were arranged for 20th April 2000. In the morning, we were visited at the Centra hotel, where we were staying, by Mr. Doug Williams of Fluidyne Gasification Ltd. He had closed down the activities and the gasifier manufacturing plant some two and half years ago and was wondering why this visit had been arranged. I had known of his work in small scale gasification through the crest.org and gasification.org net and enjoyed talking to him about the problems in small scale gasification. He had some competence, but an exaggerated impression of his competence vis-a-vis the rest of the world. Rather peculiarly, due to many of his own acts, he had created an impression of being unhelpful. While he had done many novel experiments very few of them existed as demonstration or commercial models. He felt that most governments provided lip sympathy to renewable technologies, etc.

Later we had an experience of the visit to bubbling mud pools and a home in Maori village in Rotorua near Auckland.

Montgomery Watson waste water facility

The afternoon's visit was to waste water Treatment Company called Montgomery Watson in Auckland. They treated the sewage water which flows along with the rain water into the plant. They had a primary digester which generated Methane gas which was used in dual fuel operated Merlin Engines. They were intending to change to gas turbines now with topping of the biogas by natural gas. The secondary treatment was done in a facility called Bacterial nutrient removal technique till now and were changing over to a very expensive ultraviolet technique. The total liquid flow was at the rate of 3 to 14 m^3/s (0.2 to 1.0 million m^3/day) and the total sludge removed was between 100 to 300 tonnes per day. (The concentration of the solids is between 0.006 to 0.025% - very high value compared with the inflow quality in Perth). The tertiary treatment took place in lagoons where the stay time was set at 20 days. With the new technique of ultraviolet treatment, it would be possible to reduce this to 12 hours. The liquid could be let out during the tidal receding time. On a question about the approach taken in Perth, it was indicated that the technique was indeed practised at several places. He indicated that their practice was considered not entirely proper and changes to methodology were currently being made wherever possible since such a change had a significant impact on the investment costs. For a question on the tariffs being imposed on the society for sewage treatment he indicated a value of 800 to 100 NZ dollar per household.

9.10. Summary

The single most important distinguishing feature of the technologies we saw both in Australia and New Zealand was that all the plants were extremely well instrumented for monitoring and control to the extent possible or relevant and work 24 hours a day. However, at most places it became clear that India had an edge in the development of bioresidue-based technologies – the simple atmospheric pressure air gasification along paths not taken by others in the world in handling in a single technology both woody biomass with low ash content and high ash agro-residues (through densification via briquetting to enable economic transportation) in an atmospheric pressure air gasification process by techniques which give very high gasification efficiency would pay rich dividends in placing India in a leading edge position both from the point of view of stature and economic returns through servicing these technologies in both other developing and developed world. It was considered important that MNES took initiative in this regard.

INVOLVING INDUSTRIAL PARTNERS

10.1. M/s Kirloskars and Greaves, Ltd

By 1997-1978, it was clear that we had arrived in terms of technology. We could build larger size systems with the gasification system alone posing no new issues of significance. If we had to scale up the technology outreach, we would need to transfer the (a) gasification technology and (b) provide industrially consistent power generation package. The auxiliary systems namely, biomass preparation in terms of sizing and drying as well as cooling water clean-up, load management elements (like grid synchronizing) would need to be put together in the package. We knew that these auxiliary systems were items that could be industrially sourced and there was nothing inventive about them. However, the most difficult question was engine - alternator package. For any size larger than 3.7 kWe class, we had to depend on engine suppliers like M/s Kirloskar oil engines, M/s Greaves cotton limited, and Cummins India Ltd. The possibility of dual-fuel mode operation with existing compression ignition engines at diesel/fuel oil replacements of 75% would be entirely feasible and could be considered as a straightforward alternative. But then the cost of electricity generated would be composed of diesel/fuel costs and with rising prices of the fossil fuels, this would become so significant that the dual-fuel option would not be economically meaningful package. This naturally led to hunting for spark ignited gas engines.

Our initial attempts with Kirloskar oil engines did not prove fruitful. Spark ignition engines operating on natural gas and LPG were being developed by engine companies Cummins-India, Greaves engine, India. I wrote a communication to both the Chairmen on the relevance and importance of gas engines for power generation from renewable source like biomass and the role of this technology to rural power generation. No response was received from either of the offices and Mr. Ravi Venkatesan, Chairman of Cummins India was inaccessible for a long time. In the case of Greaves, Mr. M. N. Murthy who was the technical manager was accessible. He had developed several engines on gas. One of the larger engines had been operating on biogas.

There was a two-pronged approach to inducing natural gas engine manufacturers into promoting producer gas-based engines and subsequently marketing them as another brand - a very tough exercise over a period of several years. Mr. Murthy gave us a 100 kWe class gas engine with its carburettor and governor meant for biogas for any possible development from our side. This in itself was considered a major progress. Initially we wanted to try out this engine at fixed power and so, it was adequate if it had features to enable steady operation at a specific load. The engine was operated satisfactorily at power levels of 70 kWe giving confidence that these engines can be operated well provided the hardware of carburettor-governor system was available. A question arose if we had developed both the carburettor and governor, would Greaves Ltd be interested in commercializing the production of these elements. Since there was no clarity that anybody in the management set up was interested in this aspect, the effort to persuade Mr. Ravi Venkatesan was pursued vigorously.

10.2. M/s Cummins India Pvt Ltd

After a critical conversation with Mr. Ravi Venkatesan, he agreed to visit us along with one of his colleagues, Mr. Aravind Upasani who had been interacting with Dr. Dasappa for some time. He came down to Bangalore for a visit to the laboratory. He arrived at around 9.30 am along with Mr. Arvind Upasani (Mr. Tagade was a subsequent contact person from the company) and we all sat down in the conference hall. He immediately stated that he had not had breakfast and could we arrange for it. Well, this got done and then, we presented to him the progress we had made on gasification including the Swiss scientific interaction. All these obviously made an impression on him, but his way of looking at it was that the small systems might open up opportunities for a win-win situation in the rural sector - large water pumping requirements. All-in-all, this created a solid foundation for continued interaction with their team in Pune. They released one engine at 55 kWe for testing. The 55 kWe system was supplied with governor so that the engine could be connected to the gasification system with our gas carburettor. This engine went through rigorous tests on engine performance with the gasification system. We established the result of 1000 kWh being generated in 24 hours with the consumption of 1100 kg biomass implying a good average of 1.1 kg biomass per kWh at a load of 90% nominal level. We also showed that the engine inlet remained clean after 24-hour run at the nominal load. The team from Cummins, India visited the laboratory and convinced themselves about the claims made by IISc team in terms of gas quality. They agreed to look at the possibility of supplying these commercially and this was a major win for what the laboratory stood for - ensuring that an engine company markets IISc gasifiers. A 1 MWe project at Arashi HiTech Biopower based on 5 x 250 kWe producer gas-based engines came up in Coimbatore and the engines were supplied by Cummins India with an assurance that this engine would be monitored by them over the next 18 months.

10.3. The Indian licensees

Beyond 1995, several industries approached us for technology transfer on gasification. Five of them from India received the technology transfer. Two smart looking entrepreneurs, Mr. Krishna swamy and Mr. Shiva swamy (cousins) met with me some time in 1995 and sought technology transfer on biomass gasification systems. Mr. Krishna swamy was far more energetic and argumentative, a never-give-up class individual and Mr. Shiva swamy was sober but would finally be guided by the decisions of Mr. Krishna swamy. M/s Ever green power limited was their company in Chennai. There were interesting duo and were culturally also very interesting. One of the nieces of theirs was a professional singer of significant accomplishments. They were active in promoting power generation systems. Some discussions at two meetings with all of our colleagues included led to a formal technology transfer agreement. It is they who brought in Mr. Prakash from Coimbatore for discussion on the 1 MWe power generation system. Years later much after his 1 MWe system was installed, Mr. V. S. Prakash started his own company, Arrya Hi-Tech Energy in Coimbatore and sought technology transfer. Much discussion took place before the formal tech transfer to his company. Mr. Aravindakshan of Zigma Industries was working earlier with Mr. R. Joseph when the technology transfer for 3.7 kWe system was in place. He was very competent at fabrication and would not hesitate to offer alternatives for manufacture. I used to cajole him every time he met me during his visit to the laboratory for fabricating some equipment or the other and enquire with him as to why he cannot graduate to become manufacturer. He relented ultimately and brought in Mr. Amar kumar and discussions were held on the tech-transfer process. They formed a company called Bioenergy Technology Ltd (BETEL). This was gone through after some discussions. I was personally keen on having one licensee in Bangalore because we would then have opportunity to make developments, check them out and ensure quality before the hardware would be shipped to the site (for relatively small systems). I must say this judgment was tested out and was found to be robust. They built many systems and the systems functioned to the satisfaction of the clients. Other licensees from outside locations were added and also built systems, but these companies did not last long. Several of the technologies related to clean heat were supplied. The needs of clean heat in food industries and rubber industries were met with by the gasification systems based on sized biomass.

More than half a dozen systems for electrical applications were supplied to Thailand, Brazil, Cuba, Zambia, Chile and Switzerland by several licensees manufacturing the systems in India and shipping them overseas. Most of our technicians along with Dr. G. Sridhar, Dr. H. V. Sridhar and Mr. Subbukrishna spent varying times in training the local people on operation and maintenance aspects for several weeks in these countries. In some cases, as in Zambia and in North of Brazil, one of our mechanics went there, installed the system with local help, operated the system for two weeks during which period the local people were trained. They would reach out to the laboratory only when there were major issues in maintenance.

10.4. The 1 MWe power generation system

It is interesting to appreciate the nuances of how Arashi HiTech Biopower got involved in the 1 MWe grid linked power project.

M/s Ever green power limited seemed particularly interested in promoting large grid linked power generation systems and they found Mr. Prakash Kummar from Coimbatore belonging to a political family (his father-in-law was an MLA from DMK party at that time) as an interested person. They brought him to the laboratory for discussions. We were enthusiastic with relatively small power generation systems (~ 100 to 250 kWe class) to be able to monitor and manage technical issues in the early stages. But Mr. Prakash was interested in large power levels (meaning of the order of 1 MWe. Much discussion followed and since he persisted in his dream project even after being told about the technical and financial risks involved we gave in to the demands for the large power project. Mr. Prakash went to a bank for loans. A bankable proposal was prepared by M/s Evergreen power limited and submitted by Mr. Prakash to the bank. Two teams from the bank visited us and wanted to explore the currently successful projects. We told them that smaller systems have been built and had accumulated about several hundred hours of successful operation, but large power systems had not been built. We gave them truthful responses about our abilities and commitments and did not paint a rosy picture that would be undefendable. In any case, they funded the project based on considerations that were clearly beyond us. The next two years were tough for all the people concerned - us, Mr. Shivaswamy and Mr. Krishnaswamy and Mr. Prakash. Finally, the plant got inaugurated. I will not elaborate the many hiccups that had to be dealt with at this time. The biomass chosen was coconut shell and at one time there was 600 tonnes of coconut shell stored around in the yard (the daily consumption was about 20 tonnes on the average). The plant ran for several years very well. For 18 months a team from M/s Cummins India monitored the performance and opened up the engine at the end of 5500 hours to check the quality of piston head, valves, crank case oil and other elements. After this examination they sent a formal report that the engine had functioned very well nearly comparable to a natural gas engine. This was considered a remarkable feat for a turbo-supercharged engine of 250 kWe class. This was another important milestone in the development history of producer gas-based engines.

10.5. International licensees

There were three technology transfers to overseas industrial partners. In the case of Japan, M/s Satake corporation represented by Mr. Haruo Tarui was involved. He visited us periodically and one system of 45 kWe was installed in their factory premises and Dr. G. Sridhar spent time in the installation and commissioning of the system. He also helped train several senior people in the operation and maintenance. In the case of Switzerland, Indian company called NETPRO that had received the technology transfer built and operated a system of 425 kWe.

Later a Swiss company called Xylowatt also received a technology transfer and they built a fully automated system of 55 kg/h gasifier and 50 kWe gas engine and when Dr. Dasappa visited Xylowatt to resolve some technical issues, the fully automated system was shown to be fully functional. The system was programmed in such a way that when there was any technical glitch, a message would be sent to the mobile of Mr. Pasquale Jordon, the designer of the system and engineer-in-charge and system would initiate a safe shut-down sequence. Much later, in 2007 - 2008, a technology transfer to General Electric Co was done by my colleagues, Prof. P. J. Paul, Dr. S. Dasappa and Dr. N K S Rajan. This was another important milestone in the technology development and technology transfer aspects. That the General Electric Co was interested in the technology transfer from a small section of Indian Institute of Science turned out to be a matter of genuine surprise to several faculty colleagues at IISc.

SCIENCE, ADMINISTRATION AND MANAGEMENT

11.1. Mini-Management?

I have used the word management here to refer to the top position in an organization, like the director. There are minor roles like that of being the chairman of a centralized facility where the decisions are made and are termed mini-management roles.

In times before Prof. Dhawan's directorship (before 1962), the head of the department was considered administratively senior to other faculty members and others had little role in the recruitment process. The chairman, therefore, would virtually decide which area would grow and had an overwhelming say in the recruitment process. This could lead to neglect of a newly blossoming area or could be disastrous to a faculty member who had serious divergent opinion with the head of the department.

Being a chairman of a department unlike the head of the department of earlier times is not quite a management role since most important actions are taken together with the committee of professors and most of the chairman's actions are largely clerical (somewhat like a post office forwarding papers to other offices and signing papers received from other offices to indicate that it has been seen by the chairman and pass it back to the specific faculty member) with a few aspects that would need thinking how to avoid objections! The chairman's critical role would be to represent the department constructively in problematic cases, contentious questions that put one faculty member in an unfavourable position against other colleagues even though logically, the position that the faculty member is taking was correct and occasions when the department was targeted by other bigger forces in ways that appeared unreasonable. Most of these had larger undercurrents and would also be the conversation issue when faculty walked over to the cafe for a cup of tea. It was very easy to fall a prey to the majority opinion and navigating the larger group to a "good" decision required tact and some off-line conversations with select colleagues and if done, would receive appreciation from all. It is kind of human engineering that could be a tough challenge and provided you with inner development that could be of long-term value. It is a kind of "petty tyrant" that Don Juan, the Mexican seer prescribes as a process to help inner development to Carlos Castaneda, his disciple. It is not something that one would invite, but if life's forces take you through it, it could be benefited from, particularly if there was awareness.

I had the responsibility of being the chairman of CSIC, the centre for scientific and industrial consultancy (1989 - 1991), the chairman of the department of Aerospace Engineering (1993 -1998), chairman of the CSSP, centre for sponsored schemes and projects (1996 -2003), Secretary, KSCST, Karnataka State Council for Science and Technology (1997 -1999). Of these, I would classify the chairmanship of both CSIC, CSSP and the Secretary, KSCST as with mini-management roles. In each of these roles, I intended to do something unique and distinctive within the small framework available for decision making in terms of larger good.

11.2. Science in administration?

Quite often, one would hear that a faculty member had been appointed as the chairman of a committee (short-lived), a standing committee, a centre or a department and there would be quizzical looks around indicating that the science of the particular person would suffer or could even be written off, etc. Corollaries to this observation were that administration did not call for science or practice of science was outside administration. I had found that science could be made the basis of administrative decisions on many aspects. I will bring out some aspects of science that got done in the aid of administration.

11.3. Student agitation on computer terminal access

Institute had received the IBM 360 computer and it had been just operationalized sometime in 1982. There were six terminals with attached card readers for users to process their Fortran programs punched on cards to be taken into the machine and then program run initiated and output could be printed to allow examination of results off-line. There were six terminals and there was a heavy competition among the students to get to these terminals. For this purpose the computer centre wanted the students to queue up. For some days this went on, but some late risers always were at a disadvantage. This led to widespread unhappiness and a student agitation was launched. They met the director, Prof. Ramaseshan and wanted resolution to their problems. Prof. S Ramakrishna, Prof. S. Bhagavantham's son (Prof. Bhagavantham was a student of Sir C V Raman and the director of IISc before Prof. S. Dhawan) was our colleague in the area of Guidance in the department of Aerospace Engineering and he was appointed as the Advisor to the Director. He was close to me as well as other younger faculty in the department. He brought me in for a personal discussion to find out what the issues were. I said I would find out and came back to the department and asked one of my students, Mr. H. K. Narahari who was doing computing at that time. After uncovering the reasons for the problem, briefed Prof. S. Ramakrishna. For the resolution of this problem, an executive committee was constituted with Prof. E. S. Rajagopal as the chairman, me and Prof. C. Ramakrishnan of Molecular Biophysics Unit (MBU) as the members. We met a couple of times, figured out the solution strategy. Every student should get a guaranteed number of slots every week for using the terminals. This number should be based on the approximate usage over the last few weeks/months depending on the availability of the data.

I remember that during this time, when I was sitting in my office working away with the data, one student from MBU came in panting and out of breath, and I quickly offered the seat in front and enquired what the issue was. She said she was desperate to get some computer slots since she had to get some paper out as soon as possible. I assured her that within the next few days things would get sorted out and she would get guaranteed slots and in the meantime, she might want to get a special recommendation for some slots from the Chairman of MBU. She seemed relieved that she was heard and her problem would get solved! This was the kind of desperation that seemed to have been around.

Both Prof. Ramkrishnan and myself sat down collected and collated the data and found out the relative fractions of usage of the terminals earlier and distributed about 80% slots amongst them as guaranteed slots and the rest for those who could come in the queue. Even those who have had guaranteed slots could stand in the queue to get additional slots. Cards were issued to individual users with the slots identified and they would come in at the appropriate time and occupy the terminals and use them. Within a few days of the introduction, things got streamlined. I am illustrating this just to show how science itself was used to resolve problem.

11.4. Marks to grading system

Early in 1976-1977, we received a communication for an engineering faculty meeting to discuss the introduction of a five-point grading system instead of marking system. The indicated defect of the marking system was that it was too digital to be true. For instance, a student getting 75% marks was interpreted to be superior to one getting 74% in his performance. This would not be correct because in terms of understanding it was not possible to distinguish students to that degree of fineness. This is why one needed a qualitative grading to say if some student's understanding was "outstanding", "excellent", "very good", "good", or "poor". Even if this change was agreed to, there would be questions of how the conversion should be done. A stiff course instructor might award 70% for the truly best answer and another instructor might go up to 90% for the best answer, so much so, the question would be as to how to institutionalize this variation. Much effort was put in by Prof. B. S. Ramakrishna of ECE department and Prof. R. Narasimha who were spearheading this transformation from marks system to a five-point grading system.

After two years of operation, it became clear to many that the 5 point grading system was crude. One of the additional defects of the grading system was that there was no passing grade. The passing grade value was deliberately kept just above one identified grade for satisfactory performance. This, in addition, made the instructors to be "generous" with these grades. Once a student deserving only satisfactory grade has been given a better grade (good), others who performed better than this student would naturally be given an even better grade. This kind of buoyancy ultimately led to an unjustifiably large fraction of distinctions. This was particularly serious in elective courses with smaller number of students and not that serious in large size courses. Prof. K. P Rao of the structures group wrote a brief document outlining the observations and passed it around. It appeared reasonable, but we uncovered that it was not used beyond bringing some limited awareness around. It needed a much stronger justification. Prof. S. M. Deshpande and myself thought that we should do simulation and demonstrate over the scale of all courses that a class might take and determine the nature of distortions. So, we wrote a Fortran program for simulating the marks-to-grade conversion program by including the effect of "generosity" with suitable statistics to all the sub-effects. The simulation produced effects nearly same as the observations. We went further by asking as to what changes would normalize the results to levels same as with marks as in earlier times. It was clear that two changes were required. One grade should be the same as passing grade so that "kindness" would not get passed on beyond giving them a pass grade. There was a need for one grade slightly lower than the pass grade so that those students who were considered slightly poorer than satisfactory in any course would get the justifiable grade. Below this, the only grade required was a fail grade. Beyond satisfactory we recommended four grades. Simulations showed that the match with pre-grading system was complete. Armed with this document we approached the director, Prof. Dhawan for a meeting. During the meeting we explained what we found. He argued in favour of what was current but saw the points we made and relented allowing us to present these to the senate curriculum committee to progress the matters further. We did this religiously. After two rounds of discussions the total number of grades was fixed at 7 instead of 8 grades we recommended. This was satisfactory and we felt fulfilled that we could use science on the data from an existing system and cause a change.

11.5. Chairman, CSIC

The way the responsibility for CSIC chairmanship was bestowed on me came about this way. I had just returned from the sabbatical at NASA, LaRC in Hampton, Virginia - 15th June 1989. I reported to duty on the same day. I received a call from the director's office to meet him the following day. I did that. He made very brief general enquiries and quickly came to the point. He said the chairmanship of two centres was open - CSIC and ASTRA and he wanted me to let him know my choice almost immediately. I tried to wriggle out indicating that I was deeply involved in some interesting research and could I have a year before I took administrative responsibilities. He stated No!, " Take one more day and let me know". I thought over the day and inferred that CSIC would be a better choice because it would allow much broader interaction with the faculty of the Institute and indicated to him the same evening that CSIC would be my choice. The very next day, the office order was issued on this subject and I took charge of CSIC soon after. It was not that I was unfamiliar with the tasks of CSIC chairmanship. I had long and deep interactions with Prof. M. N. Srinivasan who was the chairman for a long time - through the directorship of Prof. Dhawan and Prof. Ramaseshan. He used to get me over to the centre to discuss many ticklish issues that were faced at various points of time. Yet, when the responsibility fell on oneself, the understanding required would be of much higher degree.

There were tasks that the chairman had to carry through on a daily basis. Project proposals would come to the centre for approval and needed to be dealt with according to the category they were involved - test projects like soil analysis for the construction of multi-storey buildings, consultancy projects involving advice on a specific problem or periodically to help out issues that come to the industrial laboratory, consultancy to deliver a specific product and similar ones. The importance of the centre in the eyes of faculty was not particularly high because the science departments thought that this was not of an intellectual standard that they were involved in their scientific pursuits. Several who expressed such views were actually doing second level science - by which I mean following the track of a first level work performed or being performed elsewhere. A further argument would be made: at least they were doing systematic work using advanced instruments (even if they were mostly imported), but the engineering groups got involved in less than scientifically challenging tasks. All these observations would never be formally made, but passed around in coffee club meetings. A few of my good friends in science discipline would effectively sympathise with me for having been charged with the responsibility of chairing CSIC!

A little afterwards, I spent time speaking to the staff at CSIC requesting them to bring up past files of significance. Mr. R. N. Narahari who was acting as a personal secretary to the office of the Chairman helped me get an overall picture in a few weeks. I uncovered that there were about a thousand completed projects whose files were in various filing cabinets. I requested our colleagues to put together these project documents to be classified according to divisions (mechanical, electrical, chemical, physical and biological sciences), studied them over a month to get an understanding of what has gone on. I wanted the outstanding projects amongst them to be converted into one-page colourful pamphlets outlining the accomplishments in a catchy manner, publicized amongst colleagues within the Institute, to visitors to CSIC and other distinguished industrial fraternity outside IISc and the choice should be of IISc. With this in mind, I got a formal clearance from the director to create five different groups of faculty to review the projects in the respective disciplines and produce a list of top five projects in each field. Then, the team met under the chairmanship of Prof. E. S. Rajagopal, the senior faculty member of the Physics department and chose up to ten projects of significance that should identify the significant accomplishments of the centre to be publicized. Prof. Rajagopal was an accessible distinguished faculty member who would not hesitate to discuss issues outside limited scientific bounds. After this job got done, Mr. Narahari who seemed to be multi-faceted in talents took the responsibility to produce the pamphlets. It took nearly six months to get things done and we had a wonderful set of 10 different projects that faculty could genuinely be proud of. I made sure that several of my friends from science departments accessed these documents and expressed their views!

There were faculty who would come up with projects that they wanted to present to specific Government science departments or R & D laboratories like ISRO or DRDO. Technically Government projects were grants-in-aid most appropriately suited to CSSP (discussed below) rather than CSIC. The ostensible reason for CSIC to be the choice was that there is a deliverable product at the end of the project (not just a completion report). Many projects from DRDO and ISRO were processed through CSIC. Typically, 30% of CSIC projects were Government funded and there were a total of 100 consultants (out of 400 faculty) around that period, The consultancy projects at that time were priced between a hundred to a few hundred thousand rupees except for test projects that were priced around ten to thirty thousand rupees. In order to enhance the consultancy role, we had several meetings with possible clients and select faculty. This did not enhance the quality or the number of projects. Ultimately, the projects needed deep faculty connects.

Roughly after two years of engagement at CSIC, I thought I could not bring in new ideas and decided to step down. I approached the director and pleaded with him that I wished to step down. He agreed and suggested that I should bring up names for him to pick the next person. In two meetings the faculty member, Prof. M. V. Krishnamurthy (Mechanical Engineering department) was identified to take over from me and I moved away from this responsibility in 1991.

11.6. Secretary, KSCST

At one time, Prof. A. K. N. Reddy asked me if I would take the responsibility of being the Secretary, KSCST in 1996. I agreed somewhat reluctantly because the position was not too definitive. There was the joint secretary who would carry out most official actions and the Secretary happened to be an honorific position as an interface with the Government. I must say I was never comfortable being in that position because the staff were not greatly keen on delivering on the roles that we thought they had to discharge. I tried various techniques and was not greatly successful. There were also some differences of opinion amongst people, the resolution of which took a generous time from what I considered precious for research. Having spent some two years in this role, it appeared to me I had spent a great deal longer time. There were two general body meetings when the finance minister of Karnataka Government was to be talked to, invited and received formally for the meeting. There was the discharge of the role of the distribution of KSCST awards that was to be dealt with by the chief minister. I handled all these roles as a robot following certain protocols which were described to me beforehand. After two such award functions and other activities, I resigned happily from the position.

11.7. International symposium on Aerospace Engineering

The year 1992 happened to be the golden jubilee year (50 years after establishment) and the department decided to celebrate this event with honouring 50 distinguished alumni and holding an international symposium on Aerospace Engineering in a befitting manner. I was made the secretary for the international symposium and the chairman, Prof. A. V. Krishnamurthy indicated the he would deal with the subject of identifying and dealing the ceremonies with other committees. My tough task was made easy by the participation of colleagues in identifying distinguished performers in Aerospace engineering in India and overseas, largely in the USA. Sending out invitation letters, and ensuring their accommodation and reception appropriately, apart from arranging the program, identifying chairmen of the sessions and rapporteurs was my task. The conference was held in the large J. N. Tata auditorium that had five halls for parallel sessions. Prof. Narasimha was the chairman of the conference committee and for the inaugural function, we had invited Prof. U. R. Rao (Photo 19.7 in Chapter 19). The three-day conference was a memorable period with many of the alumni meeting each other after a long time.

11.8. Chairman, Dept. AeS Engg

This position came to me through a peculiar route. Prof. A. V. Krishnamurthy was the chairman during the early nineties. He developed a heart related problem that required surgery and a post operative care that he estimated would take nine to ten months. Since the department needed a chairman, he requested me to be acting on his behalf. As could be expected, I agreed neither reluctantly nor wholeheartedly, but out of consideration for the circumstances. The word "acting" permitted me not to take a serious decision-making role unless the matter demanded that and I would invariably involve a few colleagues to discuss and come up with suggestions for implementation. Nobody in the department thought perhaps there was even a "chairman". This went on a for a reasonably long time and the Director who at that time was Prof. G. Padmanaban and the divisional chairman, Prof. S. Ranganathan decided that they should anoint me with the the position of "Chairmanship". I agreed (as usual!). The position did not cause me any stress except on one occasion when I had to take on the entire aerodynamic faculty group on the recruitment of an Assistant Professor in the area of fluid mechanics/aerodynamics. They were in the wrong, but intended to bulldoze the chairman. This of course, I could never allow, nor would I. Historic struggle followed. I had a colleague Prof. B. Dattaguru who was formally an Associate chairman whom I briefed on the intricacies of the issues and suggested if he could handle the issue on the side-lines. It turned out that he did not succeed and I was not very sure whether he wanted to be seen flowing against the current. The responsibility fell on me. I had to call a committee of professor's meeting (called COP meeting) and bring up the subject. I brought out that the aerodynamics group could not eliminate one individual even after he fulfilled the criterion for shortlisting. Conversations were not smooth, but the COP had to agree to the inclusion. The role of other senior faculty was very passive - let-us-see-the-fun attitude. The matter was not allowed to rest there. It was blown up as though the Chairman was interested in a specific candidate. The aerodynamic part of the COP insisted on having its member participate in the selection process. There was a special meeting held by the Director with the divisional chairman and the faculty member representing the aerodynamics COP and of course, myself. Discussions took place and the regular selection interview took place including the faculty member representing the aerodynamics COP. The candidate whom the Aerodynamics group thought would be the right person did not quite perform and was not selected. The candidate I had put in effort to include into the interview process performed very well and got recruited. I felt that I had discharged the role of the Chairman to an unusual degree very few others had either faced or experienced. Also, there were occasions when the fluid mechanics group implicitly assumed that being from propulsion, I was not quite a fluid mechanics person (shall we say, in the pecking order, fluid mechanics stood higher!), I had to argue that combustion and propulsion have more complex fluid mechanics issues and if I was working in combustion and propulsion, perhaps I had more than the necessary understanding even of fluid mechanics! Shall I say, it was a bit of fun jostling around and letting colleagues know I could not be chewed!

Around the time Prof. Padmanaban retired, I thought I should also relinquish the position of Chairmanship since by that time I had already spent five years (including the two years as acting chairman). Within a few months after Prof. Goverdhan Mehta became the Director, I spoke to him and requested that I be relieved from the position of the chairmanship to which he agreed. This ended my term as the chairman of the department in late 1998.

11.9. Chairman, CSSP

CSSP, the Centre for Sponsored Schemes and Projects received grants-in-aid projects largely from Governmental agencies - The Department of Science and Technology (DST), the department of Biotechnology (DBT), the department of Atomic energy (DAE), the ministry of renewable energy sources (MNES) and whole host of other organizations. During that period, the number of organizations was around 40 and the finances received under this head was about Rs. 30 crores in 1982. It went up to Rs. 70 crores in the next fifteen years.

My entry into CSSP as chairman has a history. During 1982 when Prof. S. Ramaseshan was the director and Prof. S. Ramakrishna was the advisor, we used to have discussions on how administration could get linked to the section of sponsored schemes and projects located in the building in front of the library far away from the main administration. The accounts of CSSP were to be integrated into accounts of the main finance. This was done through transfer of files in terms of hard copy and was obviously slow. I thought we should try electronic transfer and involved Prof. N. Balakrishnan who was a research student of Prof. S. Ramakrishna and younger brother of Dr. N. Ramani and hence close to me. We both connected up the offices electronically and tried out the transfer process. Technically it was a success and Mr. Venkararamaih who was the head of the CSSP section was indeed joyous about this process. Things started to improve over a time and I wanted that the entire finance activity including the audit should be conducted with electronic transfer of files to enable responding to the growing administrative support demand of the faculty. I involved Dr. N. K. S Rajan who had an understanding of the computer related actions required both in terms of hardware and software so that he could help the administration in these activities. These progressed to an extent that substantial part of the financial and project related activities were getting managed by networked computer access even though the faculty interaction was still with hard copies. There were several issues related to projects that also needed a faculty interface and I was brought into this role. The office was being managed at that time by Mr. Mohandas (who was called MD, a nomenclature that would roughly fit him because of his excellent managerial abilities) and I played a role when it concerned faculty interface. There were periodic hiccups with computerisation and meetings were needed to deal with certain ways of introducing the information and their transfer across offices. There was one specific case that became serious.

An anonymous letter was received indicating that a purchase was being made by a specific faculty member that had some underhand dealings. One simple way was to tear it and consign it to waste paper basket. It was decided that the matter be investigated. The investigation revealed that the contents of the anonymous communication were indeed correct. I took up the matter to the Director and explained to him the circumstances. Instead of raising dust on the subject, it was decided that the matter be handled by the respective divisional chairman speaking to the faculty member and reversing the action started by the specific faculty to ensure that the specific action taken was openly dealt with in the laboratory and would obviously not get repeated. The matter ended at that stage. Another event happened when I was the chairman of the department as well. A faculty member was engaged in purchase of equipment fabricated from a firm and the bills looked “constructed” according to the office clerical staff of CSSP. When such things happened, the subject would give me creeps. As a chairman of the department, I was forwarding the bills and other documents for settlement to the office of CSSP and from here would come a communication seeking explanation that I would need to send back to the faculty member. When it happened first, I spoke the concerned faculty member and asked as to why things were being handled this way. He took offence to my enquiry and stated that he handled the bills in a straightforward manner. I had to scale up the subject to the level when I met him at the office of CSSP along with Mr. Mohandas and explained that such actions raised questions that should be avoided, etc. I believe the issues did not get repeated for some time, at least.

At that time, the mobile phones had just got introduced and some expenditure related to telephone bills had to be taken into account in the projects. There was objection to this from the tower building. I prepared a specific note stating that as progressive offices, we needed to assimilate the new technology in the aid of faculty managing the projects and the expenditure on mobile telephones be allowed to be booked against suitable heads in the projects. This got cleared by the director. These features look trivial now, but were indeed very significant at that time. I withdrew from the responsibility just a few months before I put in my papers for early retirement. It was one of the offices I relinquished last.

11.10. IISc Directors I have worked with

11.10.1. Prof. Satish Dhawan

When Prof. Dhawan was chosen to be the director of IISc, he was just 41. This was remarkable for an Institute that was spearheaded by scientists many of them close to 55 when they were chosen to be director. This decision of the Council of IISc was received by surprise by most, but dismay by a few who thought that they deserved to be the next director. Three professors, Prof. R. Krishnan from Physics, Prof. P. S. Sharma from biochemistry and Prof. MRA Rao from the mechanical engineering department went in appeal to the High court at Bangalore against the selection of the director. The case was dismissed as the Council was considered the authority in the appointment of the director and there was no violation of any procedure.

Prof. Dhawan, who was the director of IISc from 1962 to 1981 was also my thesis supervisor from 1965 to 1970. As a director and also chairman of space commission after 1974, he was a very busy person - a man of vision and right action on most matters. I have had many conversations with him sometimes along with colleagues and other times on a one-to-one basis. His style in conversation with people who came to him with proposals was to find arguments against the proposals. If the proposers were inadequately prepared to defend their proposal, they could return empty handed. This would happen for most situations. However, when the arguments were robust, he would relent and get the action done.

His most important contribution was the expansion of the Institute by recruiting about a hundred faculty at various levels, several at Professor's level. It is not that all these recruitments were outstanding, but the entire atmosphere at IISc got altered culturally through this infusion. The hierarchical structure of the departments got loosened significantly over the next five years. The youthfulness of the director seemed to have infused a different class of interaction of greater fluidity all across the Institute. My recruitment as a lecturer in 1969, promotion to Assistant Professor in 1974, to Associate Professor in 1979 took place during his period as the director. The personal promotion process involved receiving positive views from six experts, three from within India and three from overseas. During those periods, there was no procedure of letting the faculty member know what the experts said. Since he knew what the experts had said which must have been strongly positive, he had a warm feeling towards me. Sometime in August 1980, after the successful flight of SLV 3 (18 July 1980), he invited me to go with him for a review of the flight performance to the Shriharikota range (SHAR). I was surprised and of course, delighted. I remember vividly flying sitting next to him the AVRO 748 from Bangalore to Chennai and then by car from Chennai to SHAR having long conversations on many matters outside of IISc and ISRO. While I had visited VSSC, Trivandrum in 1972 and met with Dr. Vasanth Gowarikar who was the head of the solid propellants division, my interaction with ISRO scientists in areas other than solids was weak. This particular visit and exposure to many ISRO scientists paved way for them to invite me to many of the reviews and other interesting events of ISRO. The next project in line was PSLV for which Dr. S. Srinivasan, my senior in the master's course at IISc was the project director. I was invited to be a member of the review committee for the propulsion systems of all the stages of PSLV. After Srinivasan passed away due to a heart problem three-fourths of the way through the project, the associate project director, Mr. Madhavan Nair took charge as the project director.

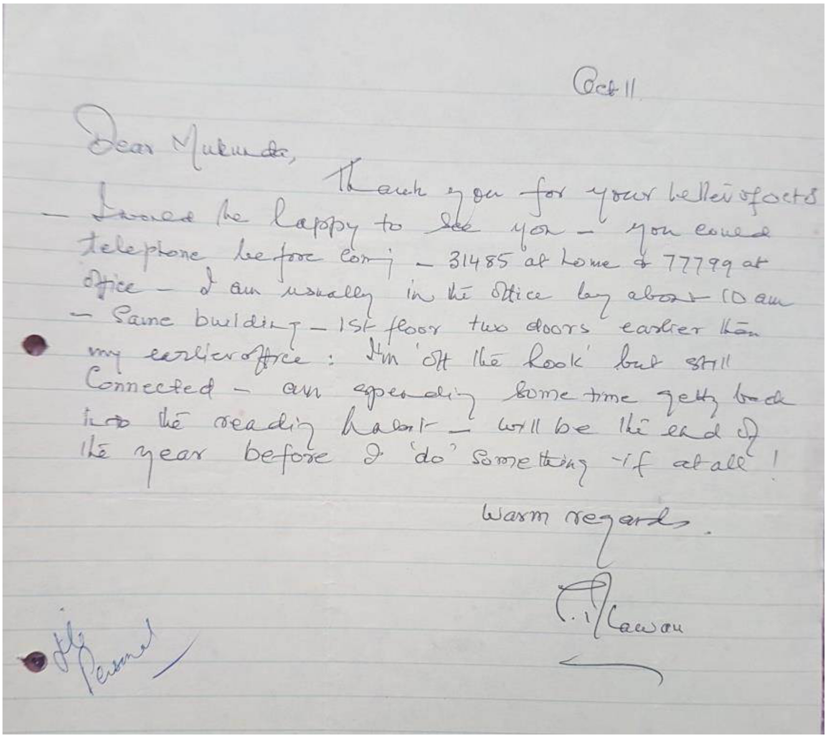
Much has been written about Prof. Dhawan by other distinguished colleagues. I would like to describe two major failings as the Director of IISc. The first failing was to give opportunity for the IISc employees union to get birth. Most of the supporting staff (called B, C, D categories) had very little opportunities for growth in terms of promotion. A loosely connected employees group was arguing with the divisional chairmen consisting of Prof. C. V. Joga Rao of mechanical sciences (former chairman of Aerospace Engineering department) and Prof. A. R. Vasudeva Murthy of chemical sciences (belonging to inorganic and physical chemistry department). When this did not succeed, there were protests and they wanted to meet with the director. Prof. Dhawan refused to meet with them. It was then that the employees went ahead and registered an association with elected office bearers. After this there were more virulent protests all across the campus. If only Prof. Dhawan had relented, met with them and also formed a group to resolve the issues in a positive manner, the association would not have got formed then. I know these facts with some certainty because, there were two persons, Mr. Srinivasiah, the head of metal workshop and Mr. Noronha, the head of wood workshop of the Aeronautical engineering department, both of whom were very close to Prof. Dhawan when he was in the department (and even after the retirement). They were deeply unhappy that the association had got formed, but they did not have access to Prof. Dhawan at the early stages to request him to be moderate and help out the employees with the possibility of promotion.

Somewhat similarly, the faculty association got formed because, faculty had serious problems of rising rents of their accommodation inside the city and like all other organizations, they wanted housing on the campus. Many discussions took place before the formation of the Association. Prof. Dhawan's argument was that living outside gave the faculty a breadth of understanding of life of the country and sanitized life in the campus would not help that. But the difficulties of rising rents and demands by house owners was also a serious issue for which there was no solution in sight. This led to the formation of the Association and the insistence of the Association to meet with the council members. Such a meeting did in fact take place and the council and the Tata trust gave money for the construction of quarters for faculty as per central Government regulations.

During the second year of the functioning of the Association, when Prof. M. V. Bhat of organic chemistry was the president of the faculty Association, I was the vice president. It was impossible for me to be virulent and I had to make arguments in way that all members should think it as rational and reasonable. There was one meeting that I attended with Prof Dhawan and when I brought up the points, he looked at the registrar, Mr. B. V. Ramakrishna and suggested that he take note of the point made and act.

Prof. Dhawan retired as the director of IISc on July 31 1981. The next director had already been appointed - Prof. S. Ramaseshan who was earlier the head of the materials group at National Aeronautical Laboratory whose director at that time was Dr. Valluri Seetharama Rao (he was normally called Dr. Valluri). There was a grand function that took place to present a farewell from faculty, staff and students of the Institute. The event was unique as a one-time event in its life of IISc because no earlier director and possibly no future director can function for so long unless somebody in forties was picked up as the director and he could last as long of four terms of a normal term of a director, the probability of both taken together is miniscule. The function was held in Jamakhana hall housing more than 2000 participants. Prof. S. M. Deshpande and myself had put together a farewell script with the help of a Sanskrit scholar that was written into a copper plaque with an English translation. I read out the script like a mantra with suitable intonations and presented to Prof. Dhawan in traditional style. It was an electrifying moment at IISc. I also participated in group singing a farewell song to which I had set the tune along with several other students and a few staff well versed in music.

This brought an era to closure. Prof. Dhawan continued as the Chairman, ISRO and secretary, Department of Space, GoI for another three more years. I had written to him wishing him well at the time of retirement from the Department of Space. He responded to me back a hand written letter as below.



Oct 11

Dear Mukunda,

Thank you for your letter of Oct 8 — I would be happy to see you — you could telephone before coming — 31485 at home & 77799 at office — I am usually in the office by about 10 am — same building — 1st floor two doors earlier than my earlier office: I'm 'off the hook' but still connected — am spending some time getting back into the reading habit — will be the end of the year before I 'do' something — if at all!

Warm regards.

S Dhawan

File Personal

Prof. Dhawan's letter to my communication on his retirement from the Department of Space

I visited him a couple of times and when I was the Chairman of the department and when he attained the age of 75 in 1995, I thought the department must celebrate by having a fluid flows workshop in which many faculty involved in fluid flows from various departments could make presentations to let him a glimpse of what has been going on for the last fifteen years (nearly). I went to his residence and spoke to him about it and requested him to honour us with his presence and participation by making some final observations. He agreed. The workshop had presentations from Aerospace, Chemical, Civil, Mechanical and materials engineering departments.

11.1.2. Prof. S. Ramaseshan

Prof. Ramaseshan had a short tenure - 1981 to 1984. It was in his time that IISc added many centres including Space technology cell and the Joint Advanced Technology program with DRDL. He was proactive and spoke engagingly with charm and wit at meetings - both formal and informal. He had a tough task of balancing the issues related to employees more than other matters and I learnt that Prof. Dhawan had told him personally that he was not leaving behind a clean situation at IISc for the successor and Prof. Ramaseshan had to deal with issues. He derived support from Prof. S. Ramakrishna, my senior colleague in the department whom he appointed formally as Advisor. It was in his tenure that my promotion to full professorship took place. He lent considerable support on activities connected to JATP of which I was the convener in the initial three years because Dr. Abdul Kalam had specially reached out to him to make it a vibrant and successful collaborative venture.

During this period, a very interesting experiment on promotions was tried. It arose out of informal conversations between Prof. S. Ramakrishna and myself and got the director's clearance and an acceptance by the associations. The essential idea was that there were services like security that were repetitive and innovation had little contribution to make to the career of a security staff. It was not that carelessness be tolerated. There would be something like normal care and alertness to subtle changes in the environment. If these were characterised then the promotion process could get simplified very much. There were personal files in which the individual performance would be recorded. The entire promotion process could be handled based on these files. Normal performance record would get promotion over a certain agreed time scale and would get promotion into higher grade pay or a higher position depending on time. Those whose record showed negative observations would remain at the same scale with penalties depending on the nature of observations. Those whose records showed exemplary conduct like detection of a theft on the campus or controlling a deviant behaviour in a small group would receive promotion into a higher grade pay scale or other appropriate cash rewards. A small committee would review the cases brought up by administration and make the decisions. There would be no need to have interviews and committees to give grades for promotion or otherwise were avoided. I was involved in this committee and was pleased about the smoothness of the operation over two years. I was quite popular for a time amongst the security personnel as it was known to them who did what and how! For reasons I do not recall, this operation did not continue later.

11.1.3. Prof. C. N. R. Rao

Prof. C. N. R Rao received his fellowship of Royal Society (FRS) sometime in 1982 and was the most distinguished and honoured scientist in chemistry. He was the director from 1984 till 1994 when retired from this position. He then created the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) of which he became the director.

As a director, his inclination to focus on research was far more intense than other segments - teaching, consultancy and others. When I was the Chairman CSIC, I had to interact with him closely. He was usually very fast in making decisions on any matter brought to his attention.

His clearances on papers also were very fast. Hence, there could be no complaints about his office on these matters. On many occasions, he was very sympathetic to financial problems that had impingement on the estate department and if he was persuaded that IISc should spend the finances, he would instantly call the concerned, find out the facts and suggest taking a positive view and clear the papers.

His emphasis on personal research in spite of being the director was so intense that it was not clear if the decision-making process on many issues was sufficiently broad based because he expected that many of these pursued by faculty members could be supported as long as the concerned faculty member was a good scientist in his view.

He was particularly supportive of me on two important occasions. I wrote the book on “understanding clean energy and fuels from biomass” and wanted a foreword to be written and thought that he would be the most appropriate person for this. I went to see him and told him about the book I had written and would he be kind enough to write a foreword. He spent some time asking me what I had written, browzed through the text in front of me and said, “fine, send me a draft and I will send the corrected version”. The draft was modified and sent across to me for inclusion.

The second event was the award of Sir M Viswesaraya award for science and technology meant for senior scientists awarded by the Karnataka Government. One day when I was walking for a cup of coffee inside the campus two senior faculty members who were coming in the opposite direction intercepted me and congratulated me. I enquired as to what had happened for me to be congratulated. then they related to me that I was recommended for the award of by Karnataka Government and they indicated that they were the committee members with Prof. C. N. R. Rao as the chairman. I thanked Prof. C. N. R. Rao at the award function at which he was present.

During the last part of his tenure, there were agitations by employees for better prospects and the decisions on these were more quickly made than was warranted in view of the long-term effects of such decisions.

11.1.4. Prof. G. Padmanaban

I had known of Prof. Padmanaban much before he became the director at IISc after Prof. C N R Rao's retirement. He was a divisional chairman, spoke well on occasions I had heard, sobriety and softness of communication were his strong points. He was an accomplished vocal musician and gave concerts on occasions (though not as a part of IISc's activities). He had the ability to see quality and distinction in academics and would not speak poorly of any person. This gained him a warmth from the academic community. He allowed debates on several crucial aspects with wider groups allowing a larger owning up of decisions.

The employee association problem was quite severe during his time. There were problems of SC/ST association that led to the formation of a committee in which I was a member and separate committee to resolve issues was also constituted and I happened to be the chairman of the committee. It is at in these meetings I learnt the art of communicating difficult negative points in ways that should be seen as reasonable even if they disliked the implications. I found that the only appropriate way was to see the middle path because in these protests and agitations, there was some substance.

The aim of the meetings would be to extract these and the evolve a solution that should address the subject from a consistent institutional viewpoint, and not as a stop-gap arrangement, as had happened in the past. A select group of agitating people were favourably treated and this had led subsequently for others to claim that they should also be treated similarly. Administrators at various levels also were also aware of these institutional deficiencies, but were helpless because the institutional issues arose out of the decisions emanating from the Director's office. The way out of this was to align the administrative procedures to Governmental rules so that internal arbitrariness was eliminated. This took several years to accomplish and happened only in Prof. Goverdhan Mehta's period of directorship.

I recall a very difficult issue that Prof. Padmanaban had to deal with. There was an employee who was involved in the SC/ST association and was unruly. He was an alcoholic and generally used abusive language. He was just being tolerated. Once he took a sharp knife and went to the table of an officer and placed the knife threateningly and told the officer that the matter he had brought up should be resolved in the way he had indicated. This became a security issue and an enquiry committee was appointed. The recommendation of the enquiry committee was to dismiss him from service. This was obviously an extreme action and the director referred the matter to the legal advisor from whom he received confirmation for dismissal. On such matters, the director had to own up the responsibility by himself and there was no way he could look for support. He took about a week's time to mull over the matter and decided to dismiss the employee. The environment on the campus was very tense around that time with the possibility of SC/ST association going into agitation mode with related consequences. Of course, the security office was prepared with the possibility of getting local police into the campus if things became too unruly. After the decision was announced, there was a weak agitation on the campus that got controlled by the internal security and the matter got resolved. I developed a deep admiration for Prof. Padmanaban because the true character of an individual would come out only under difficult situations and clearly Prof. Padmanaban had sterling qualities in this regard - ones that kept the institutional interest paramount.

He was happy to inaugurate conferences - even small ones because he stated that it was these opportunities that brought him an understanding of the field into a better focus and he would also know the participants from the Institute more closely. I had an opportunity to accompany him to Ungra, the field centre of ASTRA to enable the faculty and staff of ASTRA to present their work to him directly. He would carry a small book of Bhagavad gita and told me that it would always accompany him and he would look through it occasionally.

When he retired, he was given warm send off from several departments, a feature not extended to several other directors.

11.1.5. Prof. Goverdhan Mehta

Prof. Goverdhan Mehta as a director was not a professor at IISc earlier. He was from the university of Hyderabad where he pursued research on synthetic chemistry. He published a great deal somewhat similar to Prof C. N. R. Rao. While

I served in his regime largely in the capacity of chairman, CSSP, and had several formal interactions, I was never able to extract the technical juice of his work and therefore could not separate his quantitative accomplishments of publications and awards from the influential piece of research that he did. He would claim during early period of his becoming the director that he would come first to the office and leave it last and he had largest number of students. I thought that everybody at IISc never had only to come to office to work and work could not be expected to be completed when one left the office in an academic institution devoted to research. All were 24 x 7 researchers. Perhaps, he had in his mind less than active faculty and it was not relevant to feature them in the statement. During his period, a major achievement was the introduction of voluntary retirement scheme that allowed the Institute to reduce the number of employees significantly. The organization became lean and perhaps better fit. Issues of employee association problems became far less severe. I believe this was one of the most valuable contributions to the Institute.

I and our colleagues at CGPL had the Advanced Bio-residue Energy Technologies Society under IISc of which he as the director was the chairman. We had annual meetings and other than that, there were very few dealings of significance. During one year, we had difficulty on our MNES project and we needed financial support from the finances we had put in as royalties for a brief period to tide over the crisis temporarily. I spoke to him seeking the support. He refused point blank. He indicated that we could borrow money from banks for which I indicated that such a facility is formally not possible because we are not a company. When he indicated that we can borrow it from elsewhere, I got so upset. I told him that if IISc could not own up and support its own initiative, how could anybody else be expected to do that in other ways and perhaps it was better to close down ABETS rather than being driven along such paths. The conversation became sour and I returned empty handed. From this point onwards, the relationship was just formal.

Sometime in 2002 April, I got a call from him stating that the position of Dean of Engineering whose tenure was 2 years would become open, and I qualified because of my seniority and he would like me to accept the deanship. I responded to him stating that I did not value the position that came by seniority very much and so could I be excused from accepting this invitation. He was surprised and stated that he would like to go over with me on the matter in his office some time. I went to his office later and he made the same offer indicating further that it was a position of honour and I would interact with the members of the governing council during the council meetings (that took place quarterly and all decisions of IISc were made by the council). I indicated that I was writing a book and valued the time I intended spending on that very much more and the fact that I would interact with learned council members was no attraction for me at this stage in my life since I was intending to withdraw from IISc much before than the date of superannuation. He was further surprised and enquired as to what I was intending. I indicated that I intended pursuing answers to some questions of life and existence that were bothering me for over ten years and I did not want to keep them aside till a stage in my life when my faculties might fail me. And this needed a different class of approach to life - one of seeking freedom from as many responsibilities as possible allowing me to do things that I liked. I did not think I got across to him and could not help the situation any better. Thinking that I might change my position, he telephoned me about a month later and asked me finally if I had completely made up my mind or was, I willing to change. I stated that the mind was made up quite some time back and there would be no change.

Sometime later in 2002, it was enquired by the department that they wanted to nominate me for honorary professorship beyond retirement due in July 2005 at my age of 62. I indicated that I had intentions of withdrawing on my own from the Institute in 2003 end when I turn 60 and so I did not want to be nominated. Regarding the retirement aspect, I told them that I would make a suitable request some months in advance as required by the procedures of the Institute. Prof. M. Vijayan, the Associate director called me to his office and enquired again whether I really did not want to be nominated by the department to which I indicated in the affirmative. This was perhaps because he wanted to ensure that my nomination was not prevented by some other actions in the department.

My overall view of Prof. Mehta's stay as director is that he considered himself as a super-administrator (beyond the Registrar who is the formal head of administration) and functioned like-wise. He neither intended nor did he function to influence the science and technology at IISc. I had a distinct feeling that he had no emotional attachment to IISc and treated this as a job for the period of his position as the director. There was no matter of vision on which he took along faculty of the Institute. The start-ups that he wanted to initiate in the department of computer science and automation ran into problems a bit later and became more successful as independent entities only very much later.

11.1.6. On INFOSYS Narayanamurthy's comments.......

I watched the progress of Prof. P. Balaram as the director and Prof. N. Balakrishnan as the Associate director and subsequently with Prof. Anurag Kumar as the director. All the directors that I worked with closely and Prof. Balaram were distinguished academics, doubtlessly.

A matter of substance got into focus when Narayana murthy of INFOSYS spoke at the convocation address at IISc in July, 2015. He drew parallels with MIT (USA) pointing out inadequate innovativeness in Indian academic institutions. IISc including.

After this, there was a rush of articles by distinguished scientists – Prof. G. Padmanaban in Hindustan times on August 11, 2015, Prof. C. N. R Rao, in Current Science, 11 August 2015, Dr. R. A. Mashelkar in Current Science, 25 September 2015, Dr. Vijay Chandru, a former professor of IISc in Hindu, August 03, 2015, and several others in various other magazines. I wrote on this in Current Science in 2015 and am drawing the material from this article in what I stated then.

Prof. G. Padmanaban who spent his life time of active work at IISc and as a director for four years made two critical points. He stated "...Are we doing cutting-edge research? Not really. It is very good research, but not the breakthrough kind. Even senior scientists do not want to leave the comfort zone to risk an untrodden path. It's still 'publish or perish' that decides the future of scientists" and "…The problem with the IISc is its laid-back environment" The question that would arise would be whether anything concrete could be done about these two aspects.

Prof. C. N. R Rao had in fact suggested that if a few billion dollars were provided for, he could help create a world class university. Even if this were possible in say, five to ten years from that time, what about IISc with its long history and the dozen other science and technological institutes of higher learning of history not as long, but substantial and those established in recent times; should these be written off? I think there would be an alternate pathway I described to bring up all institutions.

Dr. R. A Mashelkar invoked lack of "irreverence" as a possible reason for lack of high-quality research. While this might well be so, if we had not seen better evolution towards irreverence over this period and no hopeful situation coming along, how long could the country wait for the right people to arrive – Was there no sure approach to obtaining results instead of unsure expectations?

Prof. Vijay Chandru brought insight from the systems in the truly successful situation in the USA explaining what might be lacking here and expressed hope of creating a structure through NITI Aayog. No matter what structure was suggested, creation of new knowledge of worth to the society around and the World at large was an act that should happen within the institution and discussions on the way forward should happen within. Inputs could come from outside but that was no argument for the lack of intense discussions within.

I intended to dwell on the core theme in the light of what was stated by these distinguished scientists indicating a missing element in each of these observations, and then would draw upon a recent history involving success in building excellence out of an existing dilapidated system and outline a strategy to grow, even if slowly, from the current situation to excellence in multiple dimensions.

11.1.7. The example - Dr.A. P. J. Abdul Kalām at DRDL

The example that I bought out was of Dr. Abdul Kalām on what he did at DRDL, Hyderabad - aspects that had not figured in any of the articles on him by many distinguished people. I was familiar with most of the scientists and directors from that time – quite often engaging them in conversations on why ISRO appeared performing better that DRDL in rocket engine-based vehicle related developments. There was a clear despondency in DRDL with most active scientists having no self-faith, feeling that nothing significant would happen in their organization. Dr. Kalām's entry to DRDL as its director in 1982 after successful SLV launch was of course, greeted with enthusiasm, but the lack of trust between product developers and users, namely, the defence services was considered a stumbling block, yet. That he created an integrated guided missile development program (IGMDP) with five different classes of missiles along with user community on board and sanctioned by the Government was in itself extraordinary achievement. Then onwards, he devoted all his time – on a 24 x 7 basis to these projects, brought to fruition with speed the most important ones. With Dr. Gen. Sundaram as the project director, Prithvi, the semi-tactical surface-to-surface missile saw its successful flight and further tests leading to interest in deployment by the army in about six years. The joy this development gave to the organization was stupendous. We must remember that the change occurred in just six years! What is crucial to appreciate is the role played by Dr. Kalām. He would engage with individual scientists at several levels and technicians in workshops at DRDL with a zeal and commitment that was simply not seen in the organization till that time. He could drive his colleagues to intense work and also show compassion at moments of personal misfortunes in ways that all those associated with him felt clearly that they were working with him and not simply for him - implying working for the country. He brought greater fame to DRDO through the realization of the strategic vehicle, AGNI over years both at DRDL and later as SA to RM. The third vehicle - surface to air tactical missile, AKASH was fruitfully completed to the satisfaction of the user community more recently and based on this, DRDL has received orders for 3000 systems – a very impressive achievement.

During the period when he was the director, he made no fundamental changes to the organization. He gave the organization what was needed most – a leadership with organizational interest the uppermost with little visible personal gains demonstrating to people at every level that they also mattered and mattered to the organization.

What would be inferences for the question on hand, namely, performing excellent science and technology in academic institutions? The analogy of Dr. Kalām was illustrative. In the case of DRDL or ISRO, the goals were clear – develop a system with specifications. It was not so for an academic. The goal was excellence in science wherever it took. In such a journey, it was possible, one would go a long way along unknown paths and could be struggling to move ahead – as it would be so for excellent scientists, but there was another extreme that was more common – being lost in justifiably significant, but, in truth, insignificant work being pursued for decades. If effort was made to let deeper reflection on the latter aspects, some who were “lost” could even be “retrieved”. I knew of many who were looking deeply inside for direction, but did not get any for long times for a variety of reasons and think that it was below their self-esteem to seek clarity from colleagues. Most importantly, excepting promotions that affected their immediate stature, there was little institutional demand for performing excellently. I discounted long or short speeches at faculty meetings when the directors made remarks demanding excellence. It was simply not clear to anybody whether such a demand was more than statutory. This was the reason for what Prof. Padmanaban described as “lay back attitude”.

What then would be the solution? Two things that directors should do – (a) interact directly with individual faculty members on a one-to-one basis for an hour or two each year exploring the broad contours of individual research - motivation for research or development, what the peers that the faculty members interact think of this class of work, does the faculty member have difficulty in getting things published, are there any serious bottlenecks in the conduct of work within the campus and offer suggestions, when possible, to get to higher levels in the exploration of the field and all that encompasses academic world. The fact that the chief executive is directly interested in his/her work becomes the strong motivating factor for individual pursuit to excellence, (b) hold meetings of small groups of academics pursuing similar subjects in a more relaxed environment along with divisional chairmen and chairmen of connected departments (senior academics overseeing progress of work and promotions) to discuss cooperative work enhancing the total accomplishments, (c) often use the presence of and distinguished academic visitors to hold similar group meetings and encourage a vibrant discussion and only make mental notes. The last technique was what Dr. Kalām used to calibrate various people including "experts" and academics, gently prodding people to perform better or accomplish more. The directors of institutions should deal with these subjects beyond administration a role that seems to occupy most for most time. It brought about close connectivity between the director or the head of institution with the faculty; it would help own up the faculty and the faculty owning up their head as academics, apart from a boss clearing papers and dealing with promotions.

It was realized by many directors after a while that there was some deadwood within their academic family. It was important that serious attempt be made to identify, nudge such people to get out of such situations. It could be far more serious with extended retirement age with full professors having an academic life of 25 years or so and can cause havoc if they are non-functional and spread an impression that the kind of life, they are living would also be worth living. Such problems cannot be resolved unless dealt with directly by the chief executive speaking quietly, gently, but surely to the individual faculty.

Further, the point made by Prof. Padmanaban on the impression that "publish or perish" attitude being dominant was sometimes denied by some directors. However, from what I have known, there was a visible broad tendency to disown developmental and technological accomplishments even if they are truly science based; and even if this was untrue, it was certainly true to say that this was the public impression. It was therefore extremely important to speak about work of significance to the nation in various relevant forums allowing the possibility for rejuvenation of broad-based academic values.

Over years, there has been decay in the functionality of segments related to contact with the industrial world. Prof. M. N. Srinivasan of Mechanical engineering department who took care of the Centre for Scientific and Industrial Consultancy laid early foundations for a dynamic and interactive place with Prof. Dhawan responsible for starting this centre. Slowly over twenty years with some ups and downs it became a reactive centre rather than a proactive one. Prof. C. N. R. Rao started the SID (initially society for instrumentation and development and later society for innovation and development) wanting a strong proactive centre for industrial interactions. For some time in early nineties, several discussion meetings between various faculty groups were held to understand the new relevant science and technology activities across the Institute. I am unaware if such meetings have taken place in the last decade. Essentially this institutional arrangement has also degraded into project processing centre in a reactive mode. Serious efforts must be made to keep the dialogue with industry alive on a periodic basis both semi-formally and formally. It is also equally true to say that interaction of academia with DRDO and ISRO is going down over time. I reflected on this at a research council meeting at DRDL, Hyderabad some time ago and suggested that they invite younger faculty to be brought in for briefing and awareness meetings. Conscious efforts must be made institutionally to keep the links with reality alive. There is no escape from reality checks for any academic work particularly in engineering science.

11.1.8. Performance as directors

How have the various directors performed on the metrics discussed above?

Prof. S. Dhawan expanded the institution by adding a large number of academics together increasing the intellectual biodiversity of the institute. By creating ASTRA, he also signalled that, approaches to functioning other than publications also could matter at the Institute. Prof. S. Ramaseshan within his short tenure, enhanced the opportunities for younger people to positions of authority through the creation of centres. Prof. C. N. R. Rao emphasized publications extraordinarily without losing sight of quality of faculty within the institution. Prof. G. Padmanaban was most accessible and allowed the possibility of greater intellectual “mixing” along the lines Prof. Dhawan had initiated. Prof. Goverdhan Mehta managed the institute to a smooth functioning system and was not concerned about deeper aspects. From what I have known, Prof. P Balaram was responsible for bringing the undergraduate program, but on the level of enhancing the quality of work, statements at the senate meetings about the quality were emphasized. By and large, the touch-me-not attitude prevailed and prevails even now.

Prof Anurag kumar did not seem to have been aware of some important features some time into his directorship.

It became clear to me in a direct meeting in 2016. The occasion was the review meeting of the National Centre for Combustion Research and Development (NCCRD) the near Rs. 100 crore initiative of DST (between IISc and IITM) and was chaired by Dr. Saraswat who had by then become Member, NITI Aayog. Dr. Saraswat, myself and Prof. Anurag kumar were seated at the lunch table and Dr. Saraswat started the conversation by saying that the aerospace department seemed to have “lost its steam” in its interaction with DRDO laboratories something that was very significant a decade earlier and enquired with the director as to what he thought about it. The director said that the department was doing very well in his view. I intervened and stated that I agreed with the perception of Saraswat and stated that I had written about this in Current Science and explained it then. In the period up to 2000, scientists in DRDL and HEMRL were on the learning curve and the intense interactions with IISc Aerospace Engineering were mutually exciting and productive. It was productive for IISc because the nature of problems could include those from real life something otherwise not possible. Once the DRDO scientists produced functional systems and successful missiles, the nature of their questions were different. In order that one could deal with these, it was firstly important for the new generation of academics to become aware of the successful systems because in the conversations between the academic and the scientist (in DRDO) the scientist would cite successful ideas from an earlier school of thought and the academic would not be able to communicate unless he was aware of the current systems. Such an awareness could come provided the academic approached the DRDO scientists with an internal humility needing to learn the successful technology. If this was bypassed with the thinking that what one knew was modern and could be sought by DRDO, there would be a gap in the bridge and this would be continuing to widen over years as I have seen several times in the meetings. I have had occasions to express this in meetings in DRDO and elsewhere, but there was no opportunity to share it with IISc. The response to this analysis by the Director IISc was one of mute acceptance.

11.1. 9. So, finally

It is to be recognized that great work happens because there is a very large pool of good scientists doing good work, large pool of scientists doing very good work and a smaller number doing extraordinary work in a pyramidal manner – Greatness does not appear in isolation albeit with a very low probability. It is often said what an institution can do is to make the right choice at the time of recruitment because there is very little that the system can do to elevate the quality of the science the person does. This is true. It is practised very intensely in many countries overseas, not much in our country. But constant urging by the chief executive to excel on an individual level is something that does not seem to have been tried. We have at least one successful model - in Dr. Kalām at DRDL and remains untried as yet in academic environment.

In the light of these, I think IISc has missed out from 1962 till now - fifty years by adopting “give me freedom to do what I want” to an extent that I do not see the level of excellence rising. No matter how many times, whichever calibrating agency says IISc is No 1 in Asia, 2 according to some other index, etc, I do not see the route to being No 1 internationally, yet.

OF SCIENTIFIC MEN AND MATTERS

12.1. Scientists overseas

12.1.1. The Russian linkage

In 1982, a delegation consisting of two professors and two scientists from CSIR were sent as a delegation from DST to USSR. Prof. Sharma of the mechanical engineering department, IIT Bombay, myself, Dr. R. A. Mashelkar, NCL, Pune (who at that time was the head of a division, but was confident that he would become director soon and also receive awards!) and Dr. Rehman from Regional Research Laboratory, the CSIR laboratory in Hyderabad were the members. Because of seniority by age, Dr. Rehman was the leader of the delegation. We visited Moscow as a transit location. We had to visit the Luikov Institute of heat and mass transfer in Minsk, Byelorussia and our contact there was with Prof. Oleg G.kutatalod and Novosibirsk where we had to meet the director, Academician Kutateladze at Thepla Physica institute. The travel to Minsk was by train and Novosibirsk which was 4000 km away, by flight. Russia is a very huge country and the time difference between Moscow and Novosibirsk was four hours (on the return jorney from Novosibirsk, we flew from Novosibirsk at 9 am, local time and we arrived in Moscow on the same day at 9 am. local time). We spent a day at Moscow after arriving by Air India flight, were received by a lady who would be accompanying us whenever we had to go to some institution and we could go by ourselves for shopping.

On arrival at Minsk railway station, we were received by Prof. Martynenko and his colleague and were taken to the hotel where we stayed for three days. Prof. Martynenko was the student of Luykov in whose name the institute of heat and mass transfer was named. Prof Martynenko who was the head of the division when we visited him became its director in 1988. We went to his laboratory and were shown around. After that we sat in his office chatting over generalities. He pulled out a bottle of vodka and said we needed to have a ceremony! He pulled out six flower like small glasses and poured small amounts of vodka into each them. He said we should all drink it together to celebrate friendship. I indicated that I had never tasted wine and did not drink. All them made fun of me and then Prof. Martynenko stated that the visit was never complete unless this ceremony was gone through and suggested that I should make an exception that day. I did drink vodka by drinking all in one go and my throat had serious burning sensation. They all laughed it off. Conversations with him revealed that Prof. Martynenko was indeed very smart and competent academic, became an Academician and was on the editorial board of the international journal of heat and mass transfer.

The next day, we were driven by him and another colleague to see a world war II memorial created for the soldiers who had died in the war. The journey through the temperate forests was wonderful and at a place where we stopped for a while, I could see some wild berries at the edge of the road into the forest. I was told that they were edible and they were indeed sweet. Two of us were invited to one of his colleague's homes and two others to another colleague's home for dinner. We had a nice time discussing the life and times in the Soviet Union at that time. One significant thing we found was that Indians have been treated as friends amongst common people.

We went back to Moscow, stayed there a day and took a flight to Novosibirsk. We were met with by an official and taken to a hotel. The next day morning, he came and took us to the Institute and taken directly to meet with Academician Kutateladze. The conversation appeared too formal and the atmosphere stifling. It looked like he was talking down to us, more particularly after he uncovered that Minsk is the lead institution in the interaction with India. He expressed his displeasure at the delegation coming to see him after Minsk and spoke condescendingly. We spent looking through the laboratories and holding discussions on the scientific aspects. During the stay there, we moved around on the streets and met with a few pedestrians with whom we had warm pleasantries.

In 1983, Martynenko and one his colleagues visited me at IISc. Apart from the visit to our laboratory, I took them around to visit the turbo-machinery laboratory of Prof. Soundranayagam as they expressed interest in this area. Prof. Martynenko asked some searching questions on turbo-machinery and my impression was that the responses were not satisfactory, certainly not my style of defending the research. We sent them over for a visit to Mysore palace and surrounding places for a day.

The conduct of Prof. Kutatelodze when we met with him remained as a puzzle for long time. I spent time researching the relative profiles of Profs. Kutatelodze and Martynenko. It appeared clearly that Prof. Kutatelodze had a far superior standing in the science of thermal physics a subject area of broader range as heat and mass transfer. The upbringing of Kutatelodze also was in troubled difficult conditions. However, even at an young age of 19 without any accompanying education, he had made scientific discoveries in heat transfer enough to excite the imagination of his contemporary academics. And he wrote books related to heat transfer. Subsequently, when he wanted to get a formal degree, he was asked to answer questions drawn from his book! when the situation was understood, he was declared having passed without any further ado.

[The interesting history of Prof. Kutataladze can be obtained from Leontev, L. I., About unforgettable Samson Semenovich Kutateladze, Thermophysics and Aeromechanics, v. 14, 2007 and thermalscience.vinca.r/pdfs/papers-2014/Rememberance-Kutateladze.pdf].

Reflecting on uncovering aspects of Prof. Kutateladze (in 2010) about whom many in the West may also have been in the dark for over 3 decades, it appeared that we know very little of the important personalities involved in the creation of new science from several parts of the World. We have had conversations on these aspects amongst colleagues at IISc and elsewhere and have inferred that the Russian way of thinking is different from those in India and the West. Two of my former friends and colleagues from DRDO - Mr. P. Venugopalan and Dr. A. Subhananda Rao (who did his masters from IISc Rockets and Missiles programme of Aerospace Engineering Department in the early seventies) both of whom were directors of DRDL (Defense research and development laboratory), Hyderabad and HEMRL (high energy material research laboratory), Pune and wore several other hats during their active life in DRDO had visited Russia several times in their career on technology acquisition aspects. Mr. Venugopalan was involved in Bramhos missile related technology and Dr. Subhananda Rao was involved with solid propellant related technology. I have been familiar with several missile technology elements of SAM 2, SAM 3 (Pechora) and SAM 6 over a long period of time. SAM 2 and SAM 3 use solid booster rockets and SAM 6 high energy solid propellant booster and solid fuel ramjets. The solid propellants from the Russian missiles had outstanding mechanical properties and performance. These were not easy to replicate because the properties depended both on the composition and process conditions. When we discussed these aspects, it became clear that the "unknown" Russian scientists and technologists in the area of propellant engineering particularly for the missiles must be truly outstanding. So also was it true for the Bramhos missile aspects.

The conclusion is that the "high" science of a developmental organization should result in a delivered product of high technology and then only it becomes a system that will get owned by the larger organization or the country. In this context, the inference with regard to the subject of Profs. Kutatelodze and Martynenko is that Prof. Kutatelodze was a scientist of much higher intellectual stature than Prof. Martynenko, an aspect that I had never understood till recently.

12.1.2. The Japanese linkage

My linkage with Japanese researchers started in 1982 when I met with Prof. Satoshi Okajima, Prof. Hiroshi Tsuji with whom I had written communication earlier, Prof. Tadao Takeno and Prof. Takashi Niioka during the period of symposium I attended. Prof Tsuji had written a paper in the 11th symposium in 1967 on opposed jet flame over cylinders and the flow near the stagnation point was very similar to what I studied for my Ph. D. I took the experimental data from the hard copy of the proceedings available in our library and compared the predictions with the experimental data on the stagnation line and found some significant differences near the surface and wrote to him with all the analysis and comparisons. He responded to me with a polite letter but no significant observations to understand the differences.

Prof. Okajima wrote to me that he would like to visit soon after we returned from the symposium in Israel (1982). As I remember, it was perhaps in 1983 that he came to IISc, stayed at our guest house, gave a talk and became friends with everybody, specially BNR. He invited BNR for a sabbatical at Hosei University on which he spent an year initially and visited the university several more times. Prof. Okajima on his behalf seemed to love IISc and India and visited more than a dozen times afterwards, nearly every year or two. He had brought his entire family to India, stayed at IISc and visited us at our home and ate lunch with us. In one of the later visits, only Mrs and Prof Okajima came to India and again we had a get-together. His daughter Ms. Aikiko (Mrs. now) spent six months under the mentorship of BNR.

Prof. Okajima had an interesting habit. He would make some caustic or strong remark of a self-depreciating kind or even comment on somebody else and very quickly laugh and say “That was only a joke”. On occasions, he would tell me “You are a famous Profiissor (as it sounded) in Japan, no, no, No, also everywhere” and immediately I would quip “That is a good joke”. He was indeed a very pleasant person. Several staff at CGPL liked him and would greet him whenever he visited our laboratory.

I was invited to give a talk at an international conference in Computational Mechanics in Tokyo in 1986. Prof. Satya N. Atluri, a former student of our department (one year later than me) who had become a distinguished professor at the Georgia Institute of Technology at that time invited me to give a talk at the conference. Dr. A. G Marathe (who did his Ph. D with Prof. V. K. Jain, my supervisor as well) was a faculty member in the Mechanical engineering department at IISc and had done some interesting computational study on air intakes. He came along with me for the conference at Tokyo and after that we stayed at Prof. Okajima’s residence for two days. The second day we were driven by one of his students and other students to a resort at the base of Mount Fuji and stayed there overnight. All of us sat for dinner at a table about 0.35 m high (typically so at homes) and conversation flowed much more between themselves than with us. We returned the next day and went to the railway station to go to Sendai to meet with Prof. Niioka. Prof. Takashi Niioka was a combustion scientist whom I had met at the 1982 symposium in Israel was also friendly with me though not as close as Prof. Okajima. We wanted to see the National Aerospace Laboratories at Sendai and I had written to him on a possible visit to Tohouku university, Sendai where he was a faculty member then. He agreed to host us and we actually stayed at his home for a day. We visited the university and the National Aerospace Laboratory and returned back to Tokyo and then to India. Prof. T. Takeno, a student of Hiroshi Tsuji was also a very good scientist with whom we could discuss several scientific aspects - both experimental and computational. My own interactions with him were very brief at the conferences during tea time conversations.

On the whole my impression of combustion science in Japan has been that they are fantastic experimental studies performed very carefully. Rationalization of the experimental data was not paid attention to as much by many such scientists. You cannot quickly get the "technical juice" from a conversation with a Japanese scientist, partly because of language barrier which on occasion is also used to stonewall the question. While any generalization is not proper, most of the work I have come across belongs to this category.

12.1.2. The American linkage

The most prominent professor from the USA with whom I (and we) have had some link was Prof. Forman Williams. The first time I came to know in 1966-67 when the book "Combustion Theory" was obtained in our library and I was excited to read it carefully since the understanding I was obtained was from a Russian book Diffusion and heat exchange in chemical kinetics by Frank Kemenetskii and the book on combustion by Spalding. It was very interesting and valuable because things that were written down followed the conservation equations and the impression was that if we solved the problems using the full conservation equations, we would get the result that should be realistic. It is not that the books by Spalding and Frank Kemenetskii were not based on conservation equations. They had simplified the equations by making suitable approximations and realistic assumptions and stated the results and it was not clear if this could be applied in more complex problems. Understanding would be well founded by carefully working through the book, particularly the initial part in combustion theory. In a way, I liked the first edition more than the second one even after the second one was released.

I am by no means convinced that studying it would lead to holistic understanding of combustion. This is because, the connect with practical experimental results is very weak and one might get a distorted view of the importance of various influences of the parameters. I found over some time, the users of numerous combustion devices in industries were blissfully unaware of even elementary combustion related issues and seemed totally unconcerned. This was one provocation for me to choose to write a simply worded book to enable wider understanding of the subject. Random feedback confirmed that this objective was fulfilled.

During the time when BNR was doing his Ph. D sometime in 1975/76, when we found some intriguing results from the analysis on droplet combustion, we wrote to Prof. Williams by sending him the document containing the analysis. That he was good enough to respond to it relatively quickly surely made us very comfortable with him as a person. This warmth of relationship that he exudes seems to have remained with him all the time. Only recently did I learn that his Ph. D thesis was on droplet combustion both mono-propellants and bi-propellants (we could not have known easily since web links were absent and only recently they were used to put out all the earlier information into public domain), the same area in which we had raised some issues.

Sometime in 2015-2016, Prof. Forman Williams visited IIT Madras to deliver several lectures on combustion to college students as a part of NCCRD initiative at IITM. At that time, Dr. Varun Shivakumar interviewed him and asked him questions concerning his interactions with people involved in combustion practice. Prof Williams apparently responded by saying that he would talk to the practitioners but not much beyond that (implying that he was not involved in practical problem solving). I consider this as limitation and not strength, because all the understanding that we might possess might in fact be a part of imagination unless and until it is founded within practice. I have personally found that resolution of combustion science related problems in practice as very enriching and acts as a great moderation on own's own feeling of "greatness of understanding". In fact, I will not miss any opportunity to engage in problem resolution be it on rocket engines, gas turbine engines, industrial combustion devices or biomass-based combustion systems. It has turned out to be enjoyable both on scientific and social fronts.

12.1.3 The British linkage

12.1.3.1 Prof. D. B. Spalding's visit to IISc

It was in 1970, Prof. Spalding visited Bangalore. He had two students - Prof. V. K. Jain, my primary thesis supervisor and Dr. B. R. Pai who was the leader of combustion group in the propulsion division of NAL headed by Dr. P. A. Paranjpe at that time. He gave a talk at IISc attended by a wide range of audience because he was well known as the person who laid the foundations for the use of computational fluid dynamics in industrial applications, particularly with regard to combustion aerodynamics. I remember that the talk was sober and professionally dealt with, but cannot say was inspiring. Perhaps the expectations were higher or different. Prof. Jain had arranged for a discussion at his office and we, his students attended it. By that time, I had got my degree and was already a faculty member, but handled myself as a person-in-transition. The meeting was again interesting, but not exhilarating - partly because I do not remember any words of wisdom in the combustion area now (or even after the meeting).

Prof. Spalding's insightful work in combustion leading to defining transfer number and model development using the most crucial aspects affecting the problem were widely recognized and appreciated. Prof. Williams apparently had sent the draft of his book on combustion theory to elicit his views. Prof. Howard Emmons of Harvard university had generally spoken about him in glowing terms. Yet, there were controversies around him partly due to the way the computational software was to be commercially dealt with. My own feeling is that the mainstream combustion did not respect him as much as I thought on his contributions to understanding combustion behaviour.

12.1.3.2. Universities of Leeds and Edinburgh

I was associated with the Fire and Combustion Research centre at Bangalore from 2009. Since I was travelling to UK to stay with my daughter's family for a few months in 2012, I thought I will use this opportunity to touch base with academics on fire research in the universities in UK. I touched base with the academics and indicated that I would like to visit them. Based on the acceptances, I went to Leeds first and then to Edinburgh which was farther away from Hereford which is where we were staying. At Leeds, fire research centre, I spent a few hours with Prof. Gordon E. Andrews and Dr. H. N. Phylaktou. I was shown around by Dr. Phylaktou and later we got together at the office of Prof. Andrews. It turned out that they have been conducting training programs for fire safety, but very little fundamental research. It was perhaps the most unimpressive environment I experienced overseas.

The visit to the fire research centre at Edinburgh was also average. Dr. Rein was the faculty member there and Prof. Torero who was the chair of the department at that time was on travel. I was told that he is the front end person getting funds for research largely. I presented my talk describing what we were doing at Jain university in terms of research in fire science and there was some discussion. I was shown around the facility after lunch. Traditional cone calorimeter was the most vital tool that they seemed to cherish. I could not get any glimpse of the fundamental issues related to fire science that they were concerned with.

12.2. Scientists - India

People I have known

I have known many distinguished and accomplished personalities in life. At IISc, Prof. R. Narasimha, Prof. E C G Sudarshan, Prof. A. Ramachandran, Dr. V Arunachalam, Dr. Abdul Kalām and a number of others.

12.2.1. Prof. R. Narasimha

Prof. Narasimha was my teacher during my master's course at the Aeronautical engineering department (it became Aerospace Engineering department in the mid- eighties). Amongst the faculty, he appeared young and had just returned from the stay at Cal Tech, USA. He spoke with a dwindling trailing voice and we had difficulty in following what he was saying. We were not sure how we should bring to his attention. We spoke to our seniors (Prof. B. Dattaguru and his class mates) and also to others so that message could go back to him. Things improved, but not a whole lot. Because of the reputation he held among everybody we knew, we took him seriously during the course. When we could independently judge something that began at the end of the first year, it became clear that he was indeed a distinguished thinker.

Among the subjects he taught us (that included basic fluid mechanics), the one that is still in my mind is the subject of Asymptotic techniques. At that time, we were also being taught Mathematics by Prof. P. L. Bhatnagar. He had ridiculed the asymptotic techniques in the class indicating that divergent series has no value in applied mathematics. I could study later the book of Meksyn on asymptotic series in the library and come to a conclusion that what Prof. Bhatnagar had indicated should be left behind.

My interactions with Prof. Narasimha were only once in a while (during my Ph. D, I was supervised by Prof. V. K. Jain largely and sometimes by Prof. Dhawan) after I became a faculty member. Things Prof. S. M. Deshpande learnt from him were often times discussed between us. There were occasions when there was a genuine serious point for which I would not be able to find resolution in the associated scientific papers, Prof. Paul and myself would undertake walking rounds the western end of the campus through the pathways between the trees for a while and if things did not find a resolution or we ended with uncertain resolution, the only person to think of going to was Prof. Narasimha, more particularly because there were very few who were deeply thinking of fluid mechanics in the department. Apart from incisive thinking, he knew a lot of literature and would cite a work by somebody that could help resolving the issue. I (also sometimes with Prof. Paul) always felt fulfilled because he would listen to the points patiently, raise subsidiary questions to help elucidate the intermediate points some of which may have been assumed as correct and this would encourage a more serious internal questioning.

Subsequent to my retirement, I found the idea of soaking the problem in the mind for a few days, allowing the mind to explore different pathways of resolution including some simple back-of-the-envelope mathematics helped receive resolutions that would appear simple afterwards!

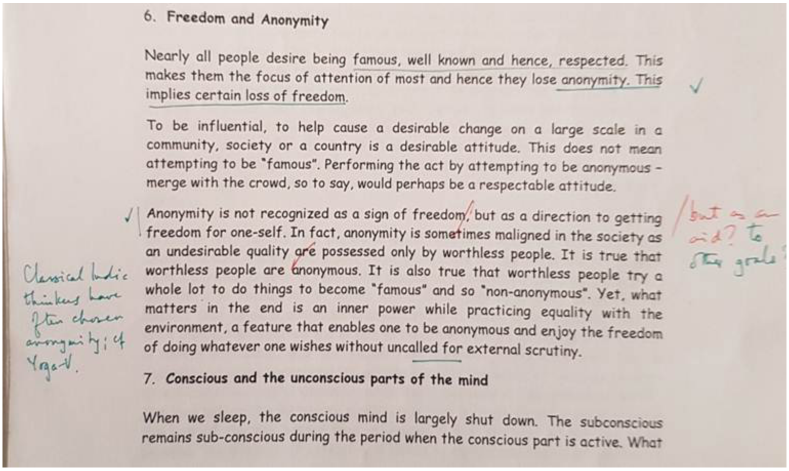
While he was the director, NAL he studied the Tipu rocket history and produced a document and also made presentations. Since I was the “rockets” person at IISc, he wanted me to explore the subject. I had also done some investigations several years earlier without much success. My aim at that time was to examine their internal geometry and to understand in modern terms as to how they were made and tested for performance. While this did not progress enough, Prof Narasimha wanted me to build some using the traditional composition (gun powder composition) and test them out at CGPL. I involved P. A. Ramakrishna when he was a research student and several pieces of hardware were built and tested. Several of them burst making cuts and bruises on the wall! Subsequently, sometime in 2015, he wanted a project to be proposed to build the rockets and I indicated that it would make sense only if we tried to build it in a manner similar to what might have been done in Hyderali -Tippu time. Periodic discussions were going on at NIAS during which Prof. Narasimha wanted the proposal to have the possibility of visiting the UK to look at the rockets in store at the Woolwich Museum and I was of the opinion that if the rockets were moved from here, there must be a large number lying around beneath the soil in the places of war and so we must enthuse archaeological survey of India to work with us on this project. We were trying to resolve this difference in the approach.

During that time, a person named Nidhin Olikara who was in Shivamogga discovered an almirah of stored rocket looking hardware in the archaeological museum. During my visit to Shivamogga I was taken to the museum and shown the almirah. It was opened after gentle persuasion that I was an expert who could say for sure that it was Tipu rocket or not. A few of those were laid open on a large paper and opened. There was intense smell of hydrogen sulphide and I immediately concluded that that this must be gun powder. I took a few of the samples and when analysed, it showed classical composition of gun powder even though the quantitatively the numbers did not look reasonable since they were lying in a well for over two centuries as the history indicated [R. Shejeshwara and Nidhin G. Olikara, The Journal of the Arms and Armour Society, Vol. XXII, No. 6, 2018]. Consequent upon these developments, the idea of pursuing the project was abandoned.

I have had brief chats with Prof. Narasimha on many occasions. On the flight from Beijing to Bangkok after the 2nd Asian congress on fluid mechanics, I happened to sit next to him. I engaged with him in conversation as to who was the most impressive scientist when he was at Cal Tech. He indicated that it was Prof. Richard Feynman and described a few aspects related to him. Curiously, I had not known about Feynman till that time. I then read up about Feynman in the book "Genius" and so many others that appeared and keep appearing on the internet. In one of the conversations that I had with him when he was on the campus for a while when he told me how one could keep intellectually engaged and also be publishing - at least two significant papers a year and therefore be seen as productive as well.

Later when I wrote "Troubling questions and beyond naive answers" an essay on my critical examination of various aspects of life, I sent him a hard copy and requested him to read and let me know his observations. Typical of him, took a fortnight and wrote his comments in red ink at several places and sent it back to me through Ms. Nagarathna who was his secretary for a long time. I preserve this manuscript even now.

Subsequently, I sought a meeting with him at JNCASR to explore some of his observations. He was kind enough to meet with me spending nearly two hours discussing several intricate aspects outlined in the writing. There were certain aspects related to the states of consciousness discussed in Mandukyopanishad on which I had made observations on which he indicated that my comments appeared new and interesting.



6. **Freedom and Anonymity**

Nearly all people desire being famous, well known and hence, respected. This makes them the focus of attention of most and hence they lose anonymity. This implies certain loss of freedom.

To be influential, to help cause a desirable change on a large scale in a community, society or a country is a desirable attitude. This does not mean attempting to be "famous". Performing the act by attempting to be anonymous - merge with the crowd, so to say, would perhaps be a respectable attitude.

Anonymity is not recognized as a sign of freedom, but as a direction to getting freedom for one-self. In fact, anonymity is sometimes maligned in the society as an undesirable quality are possessed only by worthless people. It is true that worthless people are anonymous. It is also true that worthless people try a whole lot to do things to become "famous" and so "non-anonymous". Yet, what matters in the end is an inner power while practicing equality with the environment, a feature that enables one to be anonymous and enjoy the freedom of doing whatever one wishes without uncalled for external scrutiny.

but as an aid? to other goals?

Classical Indic thinkers have often chosen anonymity; cf Yoga-V.

7. **Conscious and the unconscious parts of the mind**

When we sleep, the conscious mind is largely shut down. The subconscious remains sub-conscious during the period when the conscious part is active. What

Figure A sample of Prof. Narasimha's comments on the side of the article "Troubling questions.....answers

There were two occasions when I requested him to write a foreword for the books I wrote. In 2010, we had completed a video film and associated book "Understanding combustion through images" that in my view was the equivalent of Milton van Dykes book on "an album of fluid motion". I genuinely wanted Prof. Narasimha to examine it, provide his views and if it was agreeable to him, to write a foreword. The videos and the accompanying book were sent to him and he took about a month and simply sent a one-page foreword without further discussion. I felt fulfilled. The second occasion was when I completed the book "Understand air and space vehicles" in 2016. Here again, I spoke to him on the telephone, described briefly what I had done and desired that he examine the book, provide me with comments for any possible modifications and if everything was fine and he felt comfortable, I would desire that he write a foreword. Here again he took about six weeks and sent the hard copy with occasional remarks on some pages and indicated that I could meet him to discuss the observations. I went to his residence and spent an hour discussing some aspects of the modifications and then he opened up on Prof. Dhawan because I had written a comparison between bird flight and aircraft flight in the book. He narrated several anecdotes from the past including his interactions with the Government then and many interesting things that came out of those roles he played on the larger format of governance. He wrote the foreword that was included in the book. Serendipitously and interestingly, the time of completion of the activities related to the publication coincided with the platinum jubilee function of the department. The book was to be published by Jain university press and Dr. Chenraj Roychand, the head of Jain university desired also that it would be a fitting matter for the publication to coincide with the occasion. I requested the then Chairman of Aerospace Engineering, Prof. A. Gopalakrishnan whether he thought it appropriate if the book were to be released on the occasion of the jubilee function. He warmly agreed and the release function was graced by Prof. Narasimha and Dr. Atre (the former SA to RM). In many ways he played a critical role on important occasions in my academic career.

12.2.2. Prof. A. Ramachandran

I had known Prof. Arcot Ramachandran in 1965-1966 period when he chaired some lectures in the department of Mechanical engineering in a lecture theatre of "Power engineering". He was pleasant and used to like dealing with Q & A sessions smoothly. He was the director at IITM when I went to attend the heat and mass transfer conference in 1970 conducted there under his patronage. I had very little contact with him for the next 28 years during which period he held various positions including the executive director of the United Nations Center for Human Settlements (UNCHS). When he returned to Bangalore, he spent time at NIAS and he was involved with TERI as its chairman of the Board and several other responsibilities. He became also involved with MNES in some high-level meetings. Sometime in 1996 - 1997, the idea of having a national institute of renewable energy took shape. The Government formed a governing council for which he was made the chairman. I was a member of the governing council. This brought us closer. When MNRE gave a major project to us, we suggested that he could become the Chairman of the review committee. This allowed a closer interaction on many matters. Whenever there was a review meeting, we would prepare the progress report and we would go to his residence and provide him clarifications for any points that he thought would need an explanation. In one project Prof. V. S. Ramamurthy who was the secretary, DST was the chairman and Prof. Ramachandran was the co-chairman. When we completed the major project Strategic Development of Bioenergy, and I was intending to withdraw from IISc, we produced a book on all that we did over the earlier years to enable comprehensive understanding of the progress we had made and got the book released by him at the final review meeting. He was a generous, very well informed and very interested scientifically minded administrator apart from being an academic.

12.2.3. Prof. E. C. G. Sudarshan

Prof ECG Sudarshan came to IISc as a visiting professor taking leadership to set up the centre for theoretical studies at the invitation of Prof. Dhawan. He would visit IISc spend a month or two, provide inputs and directions for recruitment or other policy decisions and would get back to University of Texas at Austin where he was a formal faculty member. He gave lectures at IISc on physics on occasions. These were really illuminating because he spoke smoothly with simple analogies and with clarity and I enjoyed every minute of his lectures. Over years we came to know that he had deep interest in spirituality. Some of us - Prof. S. M. Deshpande, Dr. H. R. Nagendra (who was a faculty member in the mechanical engineering department, left it in mid-seventies and started a spiritual centre at a place called Jigani near Bangalore where they did and are doing experiments in yogic therapy for a large number of ailments in a systematic manner and their work is published in reputed medical journals like British Medical Journal), Prof Satyanarayana Shastry, the chemistry professor at Vijaya college (passed away about fifteen years back) used to discuss these issues and Prof. ECG was deeply impressed by Prof. Satyanarayana Shastry and there would be long discussions on Yoga Vasishta and Upanishads. On occasions, Carlos Castaneda who had written about Don Juan, the Mexican seer with whom he spent a long time learning about “spirit” would be the subject of conversation and he indicated that he would invite him to come to India and there could be more intensive interactions with him.

At some time, he virtually looked like being a disciple of Maharshi Mahesh Yogi. Maharshi was famous at that time for claiming that the transcendental meditational practice allowed people to have Siddhis like levitation. We were told that we could do a scientific study of levitation and he would get us a project to verify how the laws of physics are obeyed. We agreed to take up the challenge. Deshpande and myself worked out the strategy: Just take videos of the process and analyse them frame by frame and determine the acceleration, whether this had got any suddenly increased value in space - not connected to the ground where the momentum could be created by pushing down the leg muscles, as this process could be made significant. Prof ECG Sudarshan suggested that when he visited IISc next he would pick up the proposal for funding. We uncovered through other channels that the levitational activities were significantly progressing in Switzerland and what was going on in India was not significant. We could not decipher what the words “significant” meant and we were not hopeful of the formal test being sponsored or allowed. Some months later, Prof. Sudarshan did visit IISc, did not bring up this subject and we did not want to be very enthusiastic in seeking the funding. The matter died at this stage.

What I have felt puzzling is that a distinguished physicist who had thought through many aspects of intricate science had an inconsistent approach to spirituality or God men claiming to be spiritualists.

12.2.4. Dr. A. P. J. Abdul Kalām

The first time I came across Dr. Kalām was after he took over as the director of DRDL. After the successful SLV flight, his elevation to any significant position in VSSC was an issue because others were already in positions of significance. It was at this time that Dr. V. S. Arunachalam who was the SA to RM (he was earlier the materials group head at NAL) desired to find a suitable head for DRDL where AVM Narayanan was retiring. Back channel conversations and direct conversation of Dr. Arunachalam led to the outcome of Dr. Kalām taking over DRDL as its director in 1982. Dr. Kalām created a proposal called Integrated Guided missile development project (IGMDP) involving many missiles - Agni, Prithvi, Akash, Nag and Trishul., sanctioned formally in 1983. There was some review of a project that I was attending at DRDL during the period when the project clearance procedures were going on in New Delhi. He met with me to get an idea of the summary of the review. At that time, he made general enquiries of the activities at IISc and I indicated that Prof. Dhawan had just initiated the formation of space technology cell at IISc to enable scientific interactions between ISRO and IISc beyond the Respond program that ISRO already was in place. The essential idea of this collaborative venture was that ISRO would allocate a total sum of money to IISc and the STC would invite projects from faculty for the conduct of studies relevant to ISRO centres - VSSC, (Trivandrum,) ISAC (Bangalore), SHAR (Shriharikota), and PRL (Ahmadabad) largely. Dr. Kalām listened to me on this plan and said, he wanted a parallel centre to be developed at IISc for DRDL. I stated that he could discuss this with our director, Prof. S. Ramaseshan. He should have spoken to him and soon enough there was a visit of Dr. Kalām to the department. He met with the senior faculty and elicited their views. It turned out that if one averaged the views, one got nowhere. Subsequently, he met with Prof. Deshpande and myself and discussed the subject. After that he should have spoken to Prof. S. Ramakrishna and they must have agreed upon a plan for the establishment of a centre that was called Joint Advanced Technology Program (JATP). The MoU had core funding for an office and also for supportive accommodation for its officer being stationed at IISc, with the list of possible projects were identified amongst the major projects Akash and Prithvi. The details of the investigators of the projects and the funding for indivdual projects were also identified. IISc moved me from STC to JATP as the convenor. For the next three years, a large number of projects were completed and results flowed into the projects. There was one project with Prof. G. N. V. Rao that seemed to be functioning in a tardy way and Dr. Kalām used to call me periodically to find out about the progress on this project. I tried to determine the lapses if any, on the support side, but the lack of progress was not due to that. I figured out that there was tardiness on the part of the investigator and also that the results would not make much difference to progress at DRDL. I had to take a clear stand on the issue and told Dr. Kalām that it was only that far I could go and beyond that the aerodynamics group at DRDL would need to press hard for they wanted. Over a time, this issue got resolved rather slowly. Towards the end of 3 years, full-fledged document was prepared identifying the accomplishments in comparison to expectations in all the projects and this document was the basis of a major review of the progress of collaborative projects conducted by Prof. Dhawan in the chair. Many directors of laboratories were also members of the review committee.

Dr. Kalām was the most enthusiastic positively minded person whose faith in a person's strength was far more significant that for the failings or lapses. He would use various kinds of pressure to get things done. If he was not sure about the results of some study, he would get a team including several external members to come to DRDL and review the work. He would listen to criticisms and responses and make up his mind. This technique perhaps never failed him.

12. 3. Minimalism in combustion science

One examines the varieties of the practise of science and technology with distinguished people and others. One is forced to reminisce whether one is overdoing science with less than justifiable reasons. A contemplation leads to ideas of minimalism in science, specifically combustion outlined here.

12.3.1 At PJP memorial workshop...

In January 2015, at the 2nd PJP memorial workshop organized by Prof. P. A. Ramakrishna at Chennai, I spoke on a subject " Quantitative minimalism in combustion - diffusion or chemical kinetics". The ideas I described there arose out of contemplation over decades. When I was active in international conferences for over 20 years from 1982, when I was particularly struck by the class of questions that were being raised and researched upon. It was indeed very pleasing to hear the quality of discussion on the foundational questions. However, when I read the conference proceedings in the last decade, I found "small" aspects becoming the subject of deep investigations and the results not so significant or new in terms of expectations. This was what got me to think about what would the minimum knowledge that one should possess in order to say: I have understood the essentials and the broad contours of the subject and given a question of combustion practice, I can say something significant, perhaps even offer a solution. I am emphasizing the last part of the statement to indicate that expertise should have broader consequences, not just publications and documentation.

One might argue as some academics have indeed done, that proposing solutions in practice is the job of consultants and the role of academics is to understand, conduct laboratory experiments and do analysis and modelling. But most consultants deal with problems posed to them by looking at hand books (earlier) and internet (these days). Many problems in practice may need a deeper understanding of the fundamentals that may include experiments and analysis. And why deny oneself the joy of application of science in the resolution or problems in practice. If the central issues of practical problems are simple, they can be disposed of simply. But on occasions, one does get interesting problems that need academic attention and to lend authenticity to this attention one needs to be conscious of the essence of the fundamentals. This led to the idea of quantitative minimalism.

12.3.2. Quantitative minimalism?

Quantitative minimalism refers to extracting the appropriate elements in a mathematical functional form to create (or help) understanding. It forces one to reduce "excesses" –opposite of "taking all things into account". I remember Prof. Howard Emmons giving a talk at IISc when

I was a master's student some time in 1964-65. Somebody in the audience asked him about the effect of some variable on the results that he presented. Perhaps, he was peeved at the quality of the question and he reacted by dropping the long stick (used as a pointer) and holding at a lower position, and said, one can ask what is the influence of moon's gravity on the movement of this stick and my answer would be nothing worth accounting for. This has stuck in my mind and I am forced to think to uncover the most vital features in most problems I have encountered.

For instance, take the role of viscosity. It is unimportant for the lift aerodynamics of a wing. Not that its role is not there. Its role is to ensure that the aft stagnation point is pushed to the trailing edge and allowing the computation of the lift without worrying about viscosity. One does not need to account for viscosity when analysing for pulsation frequency in a pool fire. It is simply controlled by gravity and temperature differences. In dealing with erosive burning chemistry is irrelevant. The enhancement of burn rate is simply due to fluid dynamical effects largely accounted for by the ratio of axial mass flux divided by the lateral propellant burn flux under zero-flow conditions. Chemistry is usually very complex. Premixed flows (fuel and air are mixed before ignition can occur) are controlled by chemistry, because mixing has already occurred.

It is a subject I favoured was studying the burning velocities of some gaseous fuel-air mixtures - methane-air and hydrogen-nitrogen-air mixtures in order to elucidate intricacies of limits of flammability with complex chemistry and diffusion as discussed in chapter 3, section 3.1. This subject has grown into a large activity and Prof. Sudarshan

Kumar of IIT Mumbai has spent time in developing a new experimental technique for the measurement of the burning velocities at higher temperatures and pressures and also predicting them with complex chemistry and diffusion for a large number of mixtures over several student theses. In one of the review papers of which he is a co-author, the number of references cited is 500 indicating the vastness of the literature. I had occasion to examine if these can be simplified into a simpler correlation providing for prediction of the burning velocities for a large number of compositions and did discover a very simple approach to the predictions (one can see www.hsmukunda.in and read the paper). But this will not mean the research studies in this direction will not continue. That is because a number of journals and over a thousand researchers might lose their functional role in the field even if nothing substantive is uncovered. They need to maintain the buoyancy of the field by citing each other's publications and engage students to compute the flame structures to maintain a steady stream of students graduating with Ph. D.

Classically, one determines the constants of multi-step chemical reaction rate through fundamental experiments and these are expected to be used in engineering models for making predictions. This is what is done for making predictions of burning velocity. It turns out that the burning velocity of methane, several straight chain hydrocarbons, and some alcohols is about 0.36 to 0.42 m/s. Hydrogen-air mixture has a burning velocity of 2.5 m/s and a few others have different values. Predictions with full chemistry also deviate from experimental data in several cases. This happens so because the rate constants under certain conditions - like very fuel rich compared to fuel lean can be different since all possible pathways may not have been accounted. This can happen even if several hundred species and a thousand reactions are treated. And even if all the chemical paths are accounted for, the chemical constants can be different in widely differing regimes. This happens because some species act essentially as third body and participate in the reactive collision dynamics.

Extreme conditions like (a) high pressure and high initial temperatures as it happens in reciprocating engines, certain dominant steps may have constants different from those evaluated using standard apparatus, and (b) very high temperatures and low pressures like in hypersonic air breathing engines, the chemical constants of some step at could be different too. If the flow is three dimensional and turbulent other uncertainties of turbulence-chemistry interactions arise. Is that I am painting a very negative picture unnecessarily? A lot of work has been accomplished over the last thirty years and progress has indeed been achieved. These are not due simply to complex calculations. Inventive simplifications are sought with insight to progress the field.

12.3.3. An alternate pathway

We raise a question: Cannot we treat the burning velocity, the extinction conditions as the more fundamental features in specific conditions of interest and a very simplified - single step chemical reaction rate-based parameters derived from it. This is considered a key feature in ensuring better predictions in specific instances.

For instance, considerable success has been achieved in a rather complex problem, namely of burn rate predictions of composite solid propellants. These propellants burn close to premixed like situation at low pressures and under greater degree of diffusion control at high pressures with the additional complexity of the oxidizer (namely, ammonium perchlorate) being able to undergo self-deflagration at significant burn rate, a premixed situation. The burn rate of the propellant is known to be a complex function of particle size distribution of ammonium perchlorate, and of some catalysts. The problem was addressed over a period of two years by Prof. Varun Shivakumar and myself (see chapter 14, sections 14.5 and 14.6 for some more observations) belong the lines of single step reaction with a scaling law using experimental data. Thus, the burning velocity is considered a known quantity and the reaction rate a derived information. In this approach, detailed chemistry is avoided with no loss of predictability. This class of ideas belong to minimalistic approach - treating the problem in a simple directly relatable manner rather than a complex approach that is not very dependable either!

12.3.4. Direct numerical simulation (DNS) - to what end?

What we discussed above is laminar flames and calculation of laminar flame structure and burning velocity in one-dimensional framework. One can treat a axisymmetric version that belongs to two-dimensional geometry. Here again, laminar flame may be tackled with full chemistry and diffusion, but the size of the computation is very large. The results compare well with experiments on a broad scale and differences in composition of some intermediate species are unavoidable and are not considered vital. Such geometries are much simpler to compute even with single step chemistry assumption. They are valuable as reference calculations and not routine. When the flow becomes three dimensional and flow velocities are large (really, flow Reynolds numbers are large), the size of these calculations (DNS) grows multi-fold and can be practised in select cases to extract the essential behaviour and establish the validity of certain hypotheses. Expanding such calculations as engineering tool would not be meaningful even though some attempts in this direction have been made (under an initiative called gas turbine enabling technologies (GATET) in creating a DNS code for flow over turbine blades. One needs to simplify the approaches to perform calculations that provide useful results in meaningful time frame. Efforts in this direction qualify for a minimalist approach.

12.3.5. Pyrolysis of substances - to what end?

Pyrolysis refers to degradation of condensed phase substances into smaller fragments that get into the gas phase before combustion (or thermal conversion) happens. As different from evaporation or sublimation both of which are equilibrium processes, pyrolysis is a rate process. The fragments to which the condensed phase degrades depend on the rate of heating locally (or temperature rise rate). The rate of reaction also called pyrolysis rate is evaluated most usually by using thermo-gravimetric analysis (TGA) equipment usually found in chemistry or material science laboratories for doing this. Also advanced mass spectrometer attached to this is used to determine the nature of the fragments. These apparatuses operate at heating rates of 10 to 100 K/min. Combustion processes lead to heating rates of 1000 to 10000 K/s, order of magnitude different from the range used in the TGA experiments.

The time scales available for the degradation to occur in combustion process are way smaller than is allowed for in the TGA apparatus. Hence the fragments that come out could be expected to be vastly different.

Yet, one finds chemists and chemical engineers (as well) engaged in TGA studies on pyrolysis of fuels, biomass in particular and journals publish their work happily (!). In fact, one way of increasing the number of publications is to work in this area where everything is about crystal clear and chemistry is abound with new substances. One can keep doing TGA studies, determine the parameters of chemistry (a frequency factor and an activation energy) and increase the number of publications with little impact on knowledge of relevance. Is there no alternate way to determine the parameters of pyrolysis? Yes, there is. The experimental data of combustion at specific conditions should be treated as the data for determination of the parameters and the process of the determination could involve other computational approaches and they should be adopted to fix the values that will result in predictions that get validated in other or additional experiments of relevance. This approach arising out an understanding of the physics will replace a large number of TGA studies.

I must not be understood to imply that pyrolysis studies are meaningless. They are very meaningful when one considers phenomena that change over longer time scales - long enough to be comparable to what can be done in TGA apparatus. One example is of slow degradation of a reactive substance on storage at varying ambient temperatures, or perhaps smouldering in incense sticks or similar substances as the burn rates that are close to being two orders below that of biomass burn rates.

To me avoidance of studies that do not enlighten an area, allows answering questions of significance minimising complexity would imply quantitative minimalism.

12.3.6. Minimalism and Life

One can ask as to whether the idea of minimalism has anything to offer to life larger than scientific problems. The answer is Yes. In early stages of one's life, one wishes to acquire fame, wealth and power in varying degrees depending on the individual inclinations, the upbringing and the environment. Later in life, the value of many of these choose to exert lesser and lesser influences in the case of many individuals. One desires conditions where their own happiness which was largely derived from possessions would be less dependent on them because they experience unhappiness at the minimal absence of one of the things they have deeply depended on. One then would be led to enquire if they could be in a superior mental state if one could derive joy by not having to depend on many of these. Out of this arises the idea of minimalism. Working towards this minimalism requires asking deeper, awkward questions to within oneself that will most usually bring greater understanding and of course, sobriety –scientific or whatever one cares to be concerned about!

EXCITING INTERACTIONS - ISRO

13.1. People whom I knew from ISRO

In the early seventies, apart from Prof. Dhawan, I was weakly familiar with the Director, VSSC, Dr. Bramha Prakash, a distinguished metallurgist, a very suave functionary who spoke little but did so unhesitatingly when needed. The next series of directors, Dr. Vasant Gowarikar and Dr. S.C. Gupta were known to me. Dr. A. E. Muthunayagam, the head of propuslion group that dealt with the Viking engine along with Mr. Nambinarayanan were known to me quite well. The next series of directors, Mr. Madhavan Nair (PSLV projector director earlier and later, Chairman, ISRO), Mr. S. Ramakrishnan (he passed away about an year ago), Dr. B. N. Suresh, Dr. K. Sivan, Mr. S. Somnath (who is now the Chairman ISRO) have all been known to me quite well. Several of the directors here were the directors of Liquid Propulsion Systems Centre (LPSC) that got carved out of its existence within VSSC in 1985. There have been a large number of other active working people whom I have known more closely over a time.

At LPSC, Mr. Vedanayagam and Mr. Gopalan Nair, its earlier directors and Mr. V Narayanan, the current director have been known to me. Mr. Vedanayagam once got me over to Mahendragiri to discuss some issues related to hydrogen combustion in the late nineties.

13.2. Committee on liquid propellants for SII, PSLV

Sometime in 1978, Prof. Dhawan set up a committee of ISRO scientists with Sri. M. R. Kurup as the chairman for identifying the liquid propellants for the second stage of PSLV vehicle, the background to this being that ISRO had a collaboration with France in which 75 man-years of work could be contributed by ISRO scientists in the development of liquid engine based on storable propellants, nitrogen tetroxide and unsymmetrical dimethyl hydrazine in the engine termed VIKING engine and several scientists spent 2 to 3 years learning while working on this engine. While one would assume that the decision to choose this engine for PSLV was obvious, for reasons not clear (even now, I must say), the committee was set up to make a choice for the propellants for the second stage of the next vehicle polar satellite launch vehicle, PSLV. I was the only outside member on the committee. There were several distinguished members including Dr. Abdul Kalām, Dr. S.

Srinivasan (project director, PSLV), Sri. S. Nambinarayanan, Dr. M. Nagarajan (Head PPEG), Dr. P. R. Sadashiva, Dr. Kanakaraju, and others. There were about half a dozen meetings, sometimes at VSSC, sometimes at Shar Centre, Chennai.

The contentious point was: Should we adopt storable propellant combination and the Viking technology or develop a semi-cryo engine with kerosene and liquid oxygen as propellants. The logic for the former was that the propulsion group had acquired the technology whereas the semi-cryo engine was to be developed afresh. The counter argument was that the technology acquisition was knowledge base and the facility construction for the 70 tonne (700 kN) thrust French engine equivalent would take at least 3 years and there was enough time for building a cluster of semi-cryo engines of 7.5 tonnes class and a cluster of four engines like Russian systems would be able to meet the mission. Knives were out from both the groups (I belonged to the semi-cryo route because this would enable new technology to be home-grown). Calculations of what technology acquisition meant and how much of storable engine technology could flow into cryo-engine technology and so, how the semi-cryo option would be cheaper to design and build within the specified time because the thrust stand of 7.5 tonnes was a relatively small one to build. There was one instance when there was a lot of drama with Sri. Nambinarayanan arguing strongly for adoption of Viking engine expanding on the virtues emotionally. I looked persuaded. Dr. Kalām looked at me and said “don’t get taken in by all the dramatics”. This was one of the most enjoyable periods of discussion that involved valuation of technology acquisition - Was it drawings alone or the science behind it and if it contained the latter why should it not get counted for semi-cryo engine, and many related points both technical and not-so-technical with all the distinguished men around. Dr. Kalām made arguments that solid rocket option would be the simplest and I indicated after some other discussions that solid rocket looks simple but propellant making involves chemistry which is largely mystery! The report was submitted to headquarters and I understood that there was one crucial meeting of Mr. M. R. Kurup, Dr. S. Srinivasan, Dr. Muthunayagam, Mr. Nambinarayanan of propulsion group, and Dr. Bramh Prakash, Director, VSSC with Prof. S. Dhawan, the Chairman, ISRO. They chose the Viking engine option with storable propellants and the semi-cryo option was just dumped. What I felt distinctly unhappy about the proceedings was that the Chairman could have heard the committee's presentation along with other senior members and taken a decision then or later. We would have suggested that even with the choice of storable option, the semi-cryo option should be kept alive.

This decision became so crucial that ISRO closed the door for semi-cryo option for another twenty years and they woke up to bringing it into the loop of development seeking collaboration with Ukraine space agency. There was so much of loss of time. I am not suggesting that VSSC would have grown to the stage of building the staged combustion cycle engine of the class they are building now, but they would have made strides in understanding the semi-cryo option to a level that leveraging for new technology would have worked better to India's advantage. At a later time, Prabhu Chawla, a journalist of Hindustan times sometime in 1999 or so came to interview me regarding the history of cyro-engine development at ISRO, partly because it had lagged behind in the development. I provided the historical details as well as I knew and this led to me being a persona-non-grata for ISRO for another five years!

13.3. Instabilities in liquid rocket engines

I have been involved in the instabilities related to liquid rocket engines with ISRO on two scales - one with regard to the storable liquid engine used as a steam generator and another with regard to high thrust cryo or semi-cryo engines.

13.3.1. High altitude test (HAT) facility, SHAR

The steam generator generated steam at 20 atm to be used as an ejector fluid to reduce the chamber pressures in the rocket test bay so that high altitude rocket engine tests could be conducted. This facility was located in Shriharikota range (called SHAR). This facility was of German design with radial injector. Fuel: (Turpentine + diesel) at 2 kg/s through 152 orifices of 0.95 mm dia. Ox: RFNA – 11 kg/s through 152 orifices of 1.9 mm dia, Water: 24 kg/s; Total: 37 kg/s, Start-up: Furfural alcohol slug, Operation: steady state 12 s+ and runs for ~200 s, Nominal chamber pressure of 21 atm and down-rated chamber pressure of 19 atm.

The sporadic occurrence of pressure fluctuations argued by some as instability and others as heat transfer related problem. Apparently, the subject had a record of earlier committees with apparently no progress in understanding – confusion between thermal and instability problems continuing to persist. With the previous knowledge, it did not take me more than a few seconds to realize that it must be HFI. But proving it to somebody would always prove difficult. I brought it to the attention of Prof. Dhawan and he constituted a committee from IISc, SHAR and VSSC to analyse and find solutions. It had me as convener, Mr. Annamalai (SHAR), Mr. Ayyappan Pillai, Dr. K. Ramamurthy, and Mr. Sivaramakrishnan Nair (VSSC), PJP, BNR, and Dr. N Balakrishnan (IISc) as members. Bringing in Ayyappan Pillai who was with the propulsion group at VSSC dealing with liquid propellant instability was no problem. Dr. Ramamurthy recognized as a scientist thinking deeply about all serious issues of propulsion was inevitable. Mr. Sivaramakrishnan Nair was essentially my choice. I had long felt that he was a careful thinker and spoke only what he knew as something that could be justified with science drawn from other research studies and can be argued as appropriate. It was easy to speak to him and elicit the truth about the issues. Amongst the IISc team, BNR and PJP were propulsion people with PJP's ability in analysing the data with FFT or other methods was proven already and also, he would speak with care and responsibility similar to Mr. Sivaramakrishnan Nair.

Mr. Annamalai of SHAR had a grouse. It was that yet another committee had been hoisted on him! – he did not hesitate to state this at the beginning itself. I stated that we recognize it and perhaps he may realize later whether this was yet another committee.

During the discussions, we raised right in the beginning two important questions: Was the failure correlated with high frequency instability (HFI)? Was thermal problem the cause? - we examined the data. There were 15 useful tests. HFI data was not known for 6 tests. HF transducers were introduced later, it appears and these showed that whenever there was HFI there was failure in 7 tests. I raised a specific query with the team involved in the tests at SHAR, the colleagues of Mr. Annamalai as to whether they would hear any high pitch screeching noise. When they indicated this was so for the four of the six tests, it was clear that all of them had instability. The high frequency screeching noise has always been a well known indicator of high frequency instability. Also, when there was no failure of the hardware as was so in two tests, it was inferred that there was no HFI. This of course, received confirmation from the data analysis (called FFT - Fast Fourier Transform) to determine the spectral content of the pressure vs time data acquired at fine time intervals using a quartz crystal transducer. Many more questions were raised and answered. Some suggestions were made to overcome the instability – providing ablative liners inside the combustor to help attenuate the instability. Finally, change in O/F towards oxidizer side reduced the incidence of the instability to a low value and this appeared acceptable. Finally, Mr. Annamalai admitted that he did not imagine the degree of scrutiny undertaken in this effort would be so significant and specifically admitted that he wished to withdraw his original observation of this being another committee. The system ran for one more year and later, a new and larger facility was built at Mahendragiri close to the southern tip of India. This system remains moth-balled as most tests that needed input were completed.

Much later, Mr. Annamalai returned to the laboratory for inputs on his thesis on ejector systems for space simulation with enhanced impression of academic strength. A presentation of this problem appears in www.hsmukunda.in.

13.3.2. Semi-cryo and Cryo engines

The problem of combustion instability of LPSC in semi-cryo engines (kerosene and liquid oxygen) as well as cryo-engines (liquid hydrogen or methane with liquid oxygen) drew my attention for some time. This got re-booted due to Mr. Biju kumar of LPSC, Trivandrum who was doing his Ph. D as an external registrant at IISc with Prof. P. J. Paul. At the time when Prof. Paul passed away, Biju kumar had not completed writing his thesis. He gave me his thesis for a general reading and inputs. I was engaged with him on the technical issues related to the literature and his studies over this time. There was one question that had remained as a botheration for quite some time - full cryo engines were always less problematic and unstable compared to earth storable based liquid rocket engines. There were many arguments in the literature and they did not have a cohesive understandable explanation. There were many complex dependences drawn from experiments without adequate harmonization. After some thinking, I was compelled to recognize that the tangential mode, usually 1 T mode instability occurs in a variety of situations – high pressure storable, semi-cryo and cryo engines as well as gas turbines. So, I was pushed back in my mind to theorise and seek some common cause, perhaps not so involved in terms of the core feature that could lead to instability. Raising a question with Dr. Varun Shivakumar (my collaborator on instabilities from IIT Madras) that how could a uniform flow through a cylindrical chamber find energy source to feed on to create instability in the lateral direction, discussing and subsequent mulling over ideas reinforced the thinking that unless there was lateral inhomogeneity in heat source, lateral combustion instability could not establish itself.

That there was always a basic mechanism of dissipation through viscous forces to which we may add flow turning losses and other acoustic damping mechanisms implies that we should find it hard to create instabilities. But perception was otherwise. This meant we (all the community, I mean) were doing something wrong most of the time!

It was too well recognized and documented that shower-head class of injectors work poorly in terms of combustion efficiency, but experience rarely any instability. Russian designs with either semi-cryo (liquid oxygen – kerosene) or full cryo (liquid oxygen – liquid hydrogen) propellants, have always used coaxial injection. These imply that lateral inhomogeneity is not a direct design feature, but induced due to heat release connected expansion process. These engines have shown either full stability or much better stability of operation. Further, even smaller liquid engines based on storable propellant combinations like red fuming nitric acid (RFNA) and Aniline-Xylidiene combination used in the early Prithvi engine or later RFNA - unsymmetrical dimethyl hydrazine combination used coaxial injection but with swirl in Valient engine. Admittedly, use of swirl creates lateral velocities, but the hope was that they will get cancelled in the mean because there are ever so many small injectors on the injection face. No instabilities were encountered in this engine and this is partly due to the engine being small (3 tonne thrust). Some earlier researchers had provided many details of the Russian approach to injector design, particularly shear injector gas inside and liquid outside, liquid inside and gas outside, and use of swirl in the injection process. They finally recommend central gas core and swirl liquid injection as the most appropriate choice for getting performance and stability.

In contrast, American engines for storable propellants or semi-cryo propellants have always used impinging injectors – like-on-like (fuel-on-fuel and oxidizer-on-oxidizer) or unlike (fuel-on-oxidizer) with a variety of combinations of number of holes per injection element (a small group of impinging jets constitutes an element). They encountered instabilities and attempting to remove them created an endeavour that involved a large number of scientists and a humongous number of tests. Adoption of coaxial injection was restricted to semi-cryo engines because hydrogen that was also used as regenerative coolant would become a gas and was injected coaxially.

French (and German) designers had used radial injection for earth storable propellants– radially from the periphery. Both the high altitude test (HAT) facility rocket combustion system discussed earlier and the Viking engine (from which Vikas engine was derived) had this design. They experienced inhomogeneous distribution of heat release profile across the combustion chamber and could be expected to be unstable. Indeed, both the systems experienced instability. These systems were never proved to be dynamically stable (stability proven by decay of disturbances created by a small bomb inside the chamber after steady combustion is achieved). The correction made to the Viking engine design to improve the stability was to enhance the orifice sizes and reduce the pressure drop across the injector to maintain the total flow rates. This reduced slightly the mean performance (the specific impulse) and was accepted as such.

13.3.3. The neglected stable experiment from Germany

An interesting study was conducted in Germany on a small 80 mm diameter rocket motor with a large number of injection holes for oxygen and a porous wall through which hydrogen was injected at temperatures as low as 45 K.

The velocities used for injection are very small – very far from the observed practices. The injection arrangement resulted in an oxidizer-to-fuel ratio distribution closer to the mean. This combustion system performed with no instability over a pressure range of 50 to 90 atms with very high combustion efficiency. An alternate effort using baffles did not prove successful.

The study showed that the classical limit of hydrogen injection temperature of more than 100 K is violated seriously without causing instability. It is inferred that the near-uniform oxidizer-to-fuel distribution has contributed to stability.

Also, the derivative conclusion is that classical ideas on hydrogen injection temperature are not central in providing stability. As far as I could infer, the most crucial aspect was that the oxidizer-to-fuel distribution should be made uniform across the section.
In summary, this may be the simple paradigm in dealing with lateral instabilities in liquid rockets.

A presentation of these issues appears in the writings and presentations section in the webpage: www.hsmukunda.in.

13.4. Control system for Viking engine

In 1978, I was made a member of a committee along with Prof. I G Sarma of Computer Science and Automation department to examine the propellant control system of Vikas engine which was being conceived as identical to Viking engine of France. The control system was being dealt with by a scientist named Venkit Iyer with the propulsion group headed by Dr. A. E. Muthunayagam with his deputy being Sri. S. Nambinarayanan who was overseas in France with a team from his group aimed at absorbing the Viking engine technology while also working for them and getting paid. Subsequent to the starting of PSLV project there were many reviews of the preliminary design (called PDR). Solid and liquid rocket engines, a variety of propellants, propellant tank ullage pressurization, zero-g acquisition strategy were discussed in these reviews over a year in 1984 - 85 period. I visited VSSC as a member of the review committees for all these propulsion systems almost once every month. I was seen so frequently on the flight that some of the other ISRO people thought I was also an ISRO scientist!

13.5. Other review meetings

I was thrilled at all the meetings where sometimes young people would come up with tricky points that would create a flutter and vigorous discussion. I picked up so many ideas on the relationship of individual propulsion systems with the launch vehicle. During this period, I knew about a hundred different scientists - at all levels. I discovered that very few academics in this country or elsewhere had an understanding derived out of practical systems of this kind. I decided that all these must get condensed into writing bringing forth the relationship between fundamentals and reality, because this alone would be what provides true knowledge.

CHALLENGING INTERACTIONS - DRDO

People I have known: HEMRL, DRDL, & GTRE

14.1. HEMRL

The first time I went to the Explosive Research and Development Laboratory (ERDL), which was the earlier avatar of the High Energy Materials Research Laboratory (HEMRL) was located at Kirkee close to High Explosives Laboratory (where they were producing high explosives) in 1969 when the director of the laboratory was Dr. Patwardhan, a very kind and generous person. The laboratory had enthusiastic people - Mr. Krishnan, Deshpande, Venkatesan and others. I had gone with the students of Rockets and Missiles program at IISc. These students were composed of nearly equal number of service officers, scientists from the DRDO laboratories and fresh students from universities, about 6 each. They had visits to ERDL, Pune, DRDL, Hyderabad and VSSC, Trivandrum as a part of their course towards getting masters degree in rockets and missiles.

They were taught classes by the senior scientists from ERDL about double base propellants that were more common those days and the applications. There was one called “line mine clearing charge (LMCC)” which was essentially a long rope containing explosive charge and a small rocket with fins connected to this rope would draw th and a small pathway was cleared for the troops to walk across safely in a mine infested field. Admittedly all of us were impressed. Mr Krishnan took special pride indicating that they, the chemists also had the ability to design an aerodynamically arranged system. Of course, I did appreciate them for this development. I have been associated with many developments on solid propellants more particularly after the integrated Guided Missile Development Program (IGMDP) of Dr. Abdul Kalām got sanctioned in 1983 through review meetings on various projects under IGMDP.

I have known most directors of the laboratory including Dr. K. R Rao, Dr. A. Subhananda Rao, Dr. Bhattacharya, and Mr. K. P. S. Murthy.

14.2. DRDL

After the visit to ERDL, We went to Hyderabad which was in the early stages of infrastructural development. Mr. Nayyar and Air Com Sen were the important people with whom the students interacted. The early directors were AVM Ganesan, AVM Narayanan before Dr. Kalām took over as the director. Air Com A R Vaidya of the solid propulsion group was close to me and he was instrumental in my getting interested in solid propellant combustion, more particularly erosive burning, a subject we could contribute to over a time very significantly.

There were other directors after Dr. Kalām became the scientific advisor to Raksha Mantri (SA to RM as it was called) - Gen Sundaram, Mr. Prahlada, Mr. Chakraborty, Mr. P. Venugopalan, Mr. Sibnath Som, Mr. K. Jayaraman, Mr. M S R Prasad, with all of whom, I had considerable interactions as member or chairman of several review committees. Dr. V. K. Saraswat who belonged to DRDL took responsibility as director, RCI and soon as director general in Delhi before he became the SA to RM and subsequently, as member, NITI Aayog has been known to me for a long time even before at IISc where he was a student in the mechanical engineering department.

14.3. GTRE

I have known very closely most directors starting from AVM Roy Choudhury, a very enthusiastic and strong willed first director, Mr. Arun Prasad, next director, Mr. V. Sunderarajan, Dr. Ramachandra, Mr. Kaushal, Dr. Subhananda Rao, Mr. V. Ramanarayan, and Mr. M. Z. Siddique who is the director at this time.

14.4. Combustion instability in liquid rockets

The study of combustion instability always enchanted me from a long time because of the complexity it posed and I was engaged in the studies on liquid rockets from over thirty years (a little on hybrid rockets even earlier). The issues with motor instability on the high-altitude test facility at Shriharikota in ISRO were the first serious engagement to study the effects and influences deeply as a convener of an IISc-VSSC committee that was involved in establishing the reasons for the problem of occasional loss of the combustion chamber during the tests. Subsequently, the study of what was done on Viking engine by the French engaged the attention and assimilation. Of course, I was aware of the issues with the Valiant engine faced in DRDL by Mr. P. Venugopalan even earlier to these engagements.

14.5. Combustion instability in solid rockets - DRDL, HEMRL

Combustion instability in solid rockets, to me, was a subject somewhat distantly respected or thought understood with little serious engagement – till on 12 April 2011 when a brain-storming meeting was held at DRDL, Hyderabad – attended by all who had some link with the subject. The problem had arisen because of instability problems in LRSAM. A summary of the results of full-scale tests on LRSAM on the steady and unstable test results was presented. It was clear that changes had been made in the composition with guidance from some earlier literature and resulted in the non-resolution of the problem. What was clear was that even the steady state data had not been assimilated and beyond some frequency spectra of the data, very little examination of the relationship between the propellant and the consequence was being sought to be established on a more definitive basis. Ideas of using nozzle damping were brought up with little understanding of the differences between what happens in liquid rocket thrust chambers and solid rocket motors. Statements from experts carried very little of substance to the project authorities. One problem that was additionally posed was that the erosive burning model developed at IISc that was being used in DRDL provided unsatisfactory results for some configurations. It was indicated that this would be taken up for an independent examination if the details of the problem were provided to IISc. Data came in the form of power point presentations at various points in time and the full data of the pressure-time histories of tests was made available only in May 2013.

This needed a serious study of the literature. Internet being very friendly, allowed access to recent and early literature. Dr. Debasis Chakraborty of CFD division, DRDL who participated in these meetings took interest and sent me a hundred references. What I uncovered was that the significant experimental work in USA had been published and some valuable reports declassified. It then became my passion to read and digest this material. It almost immediately became clear that the problems of liquid rocket instability are usually at high frequencies $\sim$ 1.5 kHz or more simply because of the geometry of the combustion chamber (typically motor diameter of around 0.5 m and lengths of 0.8 m). And these are usually tangential and radial mode instabilities. In LRSAM class of motors that are about 2 m long and the port diameter of about 100 mm, the fundamental longitudinal frequencies are typically around 250 Hz. A later examination showed that most tactical motors had lengths not less than 0.7 m indicating that one could not expect frequencies more than 800 Hz, certainly not more than 1 kHz. Hence, the solution strategy of liquid rockets in so far as nozzle damping was concerned would not be relevant to solid rockets. A further serious point was that in liquid rockets, instability led to pressure fluctuations around the mean and there was no feature like DC shift common with longitudinal instability in solid rockets.

It was simply clear that DC shift mode of instability should involve large areas of propellant surface to provide the large mass flows required to increase the pressure to large values, a feature that could be inferred to be consistent with the long wave lengths of pressure fluctuation with the low frequencies involved. Mr. Varun Shivakumar (later Dr) who had just then submitted a thesis for Ph. D at IISc began to take active interest in a study of this problem in early 2012. Long walks through the campus with vigorous discussions coupled with modelling studies, calculations, comparisons with experiments ensued over the next fourteen months when he remained on the campus for the completion of the formalities for acquiring the Ph. D. This entire activity was a satisfying self-inspired unfunded piece of work continuing so till a time Dr. Varun Shivakumar left to Ropar to take the academic faculty position in early June 2013. A presentation to a meeting called by Mr. Chakraborty, the then director, DRDL (with some members from HEMRL as well) was made on 12 April 2012 by Mr. Varun Kumar and myself outlining what had been learnt and what routes to take next. One thing that was emphasized was that the data analysis had to be undertaken to a much higher degree of fineness to enable us to learn from the tests. And these could be undertaken by us if the data was made available.

From the limited information available in the power point presentations, a task that was undertaken was to compute the instantaneous mass flows with DC shift and hence seek a mass balance between the one-dimensional mass flow balance of the rocket motor. This study showed that with the same burning area, instantaneous burn rates would be as high as 100 mm/s during the periods of pressurization and burn rate to go to zero during a part of the cycle when pressure is dropping since the depressurization rates would be far beyond those for extinction reported for this class of propellants. This almost immediately led to a study of the processes of pressurization-depressurization in propellants. These results were presented to a committee chaired by the then Scientific Advisor, Dr. V.K Saraswat on 10 March 2013. Around this time other motor developments like of SRSAM and ASTRA missiles were taking place. In the view of these development groups, they had solved the instability problems significantly. It was indeed necessary to combine the understanding and the approaches made in their efforts. This led to the constitution of a committee to study the problems of instability with LRSAM as the principal focus.

14.6. Steady combustion and its linear stability as the origin

The next thought process considered then was to utilize the linear stability study to explain the observed differences in stability by treating the propellant as homogeneous by deriving equivalent parameters like the heat release at the surface, the activation temperature and specific heat along with the steady burn rate law. In order to benefit from relating the burn behaviour of ingredients to those of the propellant, an interesting diagram of the burn rate vs pressure of many model propellants was set out along with that of AP. This showed a behaviour that did not seem to have been recognized in literature. Fine AP (~ 1 and 7 micrometers AP) based propellant and AP itself had similar pressure indices (~ 0.76 ± 0.01) but the burn rate at 68 atms is 32 mm/s for fine AP based propellant and 8.4 mm/s for AP. Many composite propellants with a bimodal AP distribution (30 to 50 micrometers fine and 200 to 400 micrometers coarse in 1:1 to 1:5 ratios) had a pressure index of 0.3 to 0.4 but the burn rate usually more than of AP at 68 atm. Some propellants tended to have low index towards higher pressures to an extent that their burn rate was lower than of AP beyond a pressure of 40 to 70 atms. Based on the many studies of burn behaviour, it was recognized that high pressure burn-behaviour of AP based propellant was close to that of AP at higher pressures. If the burn rate had to fall below that of AP itself, clearly some heat absorption processes should prevail close to the surface. It was also noted that the burn rate going below AP occurred due to certain ingredients that led to melt layer. Typically, titanium dioxide, zirconium silicate, and/or strontium carbonate are added to the propellant to reduce the pressure index while not utilizing all the advantages of particle size distributions to manage the pressure index of the propellant. These ingredients were known to create a non-reactive melt layer that reduced the heat transferred to the surface between solid and liquid phases. This was supposed to reduce the pressure index. Thus, it appeared that even by design, the propellant had a liquid layer during its combustion. While strand burner studies and those that simulate steady combustion would run smoothly, it was not so obvious what would happen if the propellant experienced pressure oscillations. It was speculated that the small pressure oscillations naturally present in the combustion chamber led to an oscillatory liquid layer behaviour. That this oscillatory behaviour of the liquid layer would lead to oscillatory heat release near the surface was the summary of the speculation.

Model simulations showed much higher response function compared to a fixed heat release which is valid for a dry surface. This was considered a serious issue. If the propellant were also to have an active ingredient like RDX, the behaviour of the liquid layer might worsen the situation at reasonable fractions. These speculations needed to be explored in specifically designed experiments and therefore, there was much room for creative experimental and modelling effort. A concomitant result that came out was that if the propellant burn rate was chosen at a value close to the AP level (8 mm/s), the chances of instability could be reduced. A further feature that emanated from the data was that by choosing thermal diffusivity by altering ingredients that retained the same response function vs. dimensionless frequency parameter behaviour, one could aim to shift the response to a lower level and help overcoming the instability. A wrong way of changing the thermal diffusivity could even enhance the instability. Unfortunately, in the several guidance notes provided by Blomshield, a very significant piece of work, these fundamental features did not appear quite possibly due to the non-recognition or inadequate recognition of the importance of the thermal diffusivity; inevitably, recipes might be chosen in the wrong way without necessarily realizing that such an unfavourable path had been taken.

When Mr. Varun Shivakumar (now Prof. Varun Shivakumar at IIT Madras) was completing his Ph. D at CGPL and while he submitted his thesis, I involved him in starting to think about instability in solid rockets after I returned from DRDL meeting where this problem was discussed in great detail in November 2012. Subsequently, due to various interventions, a joint working group to study the results of static tests at DRDL and discuss ways of overcoming the instability was created. Much progress on this took place over several years and the issue of instability was overcome with changes in composition. During this period Dr. Varun and myself had discussed the subject intensively and came to the conclusion that the instability that started as linear small fluctuations developed into major non-linear oscillations and what was more important than the large oscillations was why the small fluctuations almost always present inside any rocket motor increased in amplitude. This subject when translated in ordinary language would be the study of linear stability of the steady state. Since the steady behaviour (implying burn rates) of the combustion of solid propellants depended on the actual composition, the predictive model had to be dependent on the composition. This was such a tough call because no such model existed in literature for us to draw upon nor could we wish the problem away. We were yet not ready to say we have understood the problem of solid propellant combustion instability and this made us unhappy. So, we began building the model from a very different perspective, capturing the essentials and constructed step-by-step, ensuring that the model elements were robust - comparing as many fundamental features with observations as possible.

Between 2015 and 2017, Dr. Varun Shivakumar and myself spent time addressing this issue in connection with attempts to create models and resulted in work that was published and is in the process of being absorbed both by the space and defense departments in our country. This work, in my view, has one of the finest pieces of research that has had very substantial outreach in practice. Today, propellant engineering can begin with a statement of expectations on burn rate and evolution of the composition handled on the computer before the propellant engineering begins and Dr. Varun Shivakumar will continue to be the guiding light for upgradations to the model.

THE BOOKS I WROTE AND WHY?

15.1. Understanding combustion

The first book that I wrote was a small one on combustion. It came about this way. I received a letter from Prof. K A Padmanabhan who was a professor of metallurgy at IIT Madras sometime in 1985 stating that they are starting a series of book publications titled “IIT Madras series in Engineering” and would I agree to write a book on combustion (I came to know of him and him directly as well later and in fact, did work with him during the period he was the chairman of the research advisory council of DRDL Hyderabad and I was a member). I thought it was an interesting opportunity to communicate the essentials of combustion science in simple words and in a small book so that readers will get attracted to pick it up and read. I agreed to write the book. At that time during one of the meetings with Prof. C. N. R Rao, the director at that time, I mentioned this and he stated that it was a good idea and he himself has written a small book on chemistry. Most books available at that time (and even now, for that matter) are voluminous and are meant for academics largely. Writing this book took some six months and I sent off the draft to several of my colleagues for letting me know the readability of the book and to some on its contents. Based on the suggestions I received, I modified the text and sent away the final version to Prof. Padmanabhan and this book called “Understanding combustion” got published sometime in 1988. I would hear of its readability from odd people at times when I went to a conference. Somebody would come up and let me know that he had read the book and it was simple and readable. About one and half decades later, I thought that the book needed more material particularly coming from new science and technologies we developed for biomass. And also, about explosives in a simple and explanatory style. Two chapters were added with other editorial changes and this became the second edition.

15.2. Books on Propulsion

Two books on aerospace came about later. It was in the tradition of the department to pay greater attention to research than to teaching, partly originating from the consideration that faculty promotion would strongly depend on publications and it would be enough if courses are handled, well or otherwise mattered not much. But I discovered that teaching with enthusiasm without a “wellworn" written notes with each new batch being thought as a new group with different background to educate with new or different ideas added great value. Some of the better students would wish to get on to research in these areas.

15.3. Understanding Aerospace chemical propulsion

The book on propulsion - more specifically, chemical propulsion called "Understanding aerospace chemical propulsion" and another on aero-space vehicles called "Understanding air and space vehicles" were a consequence of my teaching the courses on combustion and propulsion of air and space vehicles over years with the expectation such a book would add value to engineers moving from aeronautical organizations to space and missile vehicle development organizations. Of course, students in these disciplines in other universities could always be expected to benefit. Much of what I had learnt in ISRO and DRDO came into these books. The book on Aerospace chemical propulsion came out in 2005.

15.4. Understanding Air and Space Vehicles

The book on air and space vehicles came about because of another piece of action. Way back in 1970's it was felt that the rockets and missiles and aircrafts were treated as separate, distinct, non-overlapping fields. This, some of us in the faculty felt was untrue. Even if some aspects needed distinct approaches to understanding and design, there were several commonalities that should be understood and communicated. At that time, I gave an elementary course on aeronautical and space vehicles to research students (largely) so that their appreciation for finely engineered systems become better. Unfortunately, it did not continue due to many changes in the department at that time. Later, in 1997, this issue came up again because it was found that the research students showed very little understanding of the deep changes taking place in aeronautical and space segments in India at that time. Successful launch of PSLV, realization of LCA had occurred and it was thought these should be part of the broad understanding of the research students when they go out of the department. That it was unlikely to be so was a matter of concern. To overcome this, a course of a nature similar to the earlier one but with advances that took place in India and elsewhere was to be included. As such, I got an opportunity to offer a course on aeronautical and space vehicles with all disciplines - aerodynamics, structures, propulsion, performance, guidance and control being highlighted as to what aspects are important where and how. This was delivered for three years before it was passed on to other faculty for the conduct of the course. This was the part of the book that got published during the platinum jubilee of the department (2017).

15.5. Understanding clean energy and fuels from biomass

The work on biomass had been going on at CGPL from 1981. One of my colleagues Ms. Gayathri at our lab used to go out to schools and colleges in Karnataka in program called REACH - Renewable Energy Awareness Campaign for the masses along with a few of colleagues and KSCST (see G. Sridhar's article in chapter 20, section 20.1). She had uncovered the need for a book on biomass devoted to science and technology developments in India for substantial parts of which we had contributed. I had given talks within India and overseas and gathered enough international experience on the subject. She had been reminding me gently periodically and I decided to undertake this task sometime in 2006. Subsequently, I spent time in putting together the work we had done and gathered the work from other countries and wrote up the book on clean energy and fuels from biomass. This was published by Wiley, India in 2009.

15.6. Understanding combustion through images

When I was completing the second edition of the book "Understanding combustion", a thought crossed my mind that we do not have a book in combustion that has images like the book "An album of fluid motion" by Milton van Dyke. This appeared highly surprising because the academics working in combustion are far more self-conscious about the fact that they are addressing a smaller part of the subject of fluid flows and usually wish to assert their specialty. I thought I must do something to correct the situation. I spoke to Mr. Prahlada, the then director of DRDL and suggested whether he could give a project to the laboratory to Prof. Paul for an outlay not exceeding Rs. 10 lakhs for the conduct of experiments and putting together a document and produce a video describing the principles of combustion of gases, liquids and solids since in at least as far as combustion is concerned, seeing colourful behaviour will truly be educational if accompanied with a description of the phenomenon. He agreed and a project got sanctioned. There were three good students with enough background to "engineer" the experiments and take still pictures and videos. Mr. Varun Shivakumar, Dr. N K S Rajan's student, Mr. Arvind Iyer and Mr. Abhishek Bhat, the students of Prof. P. J. Paul all of whom were students at CGPL in later stages of their work on their theses were involved in the design and conduct of the experiments. Mr. Arvind Iyer who had special talent in manging the software produced some impressive and delightful videos of droplet combustion with an inset showing the variation of the square of the droplet diameter with time.

MEDIA EXPOSURE

16.1. A local journalist

I neither sought media exposure nor hesitated to deal with one when I need to take on.

During the mid-eighties when I was involved with defence laboratories, I was doing experimental and mathematical modelling studies related to rocket propulsion. Also, I had got involved in rural energy largely on biomass stoves and biomass gasifier - reciprocating engine - alternator-based electricity. This must have got some journalists confused as to what kind of{\it species am I to deal with seemingly destructive and constructive activities at the same time!} I was quizzed on this subject intensely. I had indicated that I am a person scientifically trained in the area of combustion of solids, liquids and gases and feel competent to study any challenging problem (s) in the broad areas and see no conflict whatsoever. We must understand that defence of the country has layers that involve both the front line and the back end. The back end is the research and development area. Every country of significance has it and it is only legitimate that we should have. Thus I feel as at home in attempting to resolve the technical problems of defence as with rural energy problems. Fortunately, I was quoted properly and I did not have any issues due to this publication.

16.2. The eventful ISRO related events

There have been two media related events that made me a unique person in India! Many senior scientists thought I was throwing away my chances of upward mobility in terms of public perception as a possible outstanding scientist by my being critical of ISRO in very unsavoury ways! It is only here that I can explain "my" side of the story to posterity.

16.3. From Hindustan Times

I was approached by Mr. Prabhu Chawla who was a journalist of Hindustan times newspaper based on the suggestion of Prof. R Narasimha who was the director of NAL at that time and also a space commission member sometime in 1991. He enquired about the delay in the cryo-engine development in ISRO. Dr. U. R. Rao was the chairman, ISRO at that time. Mr. Prabhu Chawla spent an hour with me exploring my links with ISRO at that time. I explained the entire background that I have already described in chapter 13. He went ahead and published an article in Hindustan Times and it was also picked up other papers. It was a time when the parliament was in session. There was much furore in the Lok Sabha and I learnt from my friend who was the scientific secretary to the Chairman described to me the difficulty they were having in tracing back the documents and whether I could actually provide a copy of the report. By this time, the matter was a decade old and I gave him some details which I could trace. This made me a not-too-good-a-friend of ISRO which indeed I was till then.

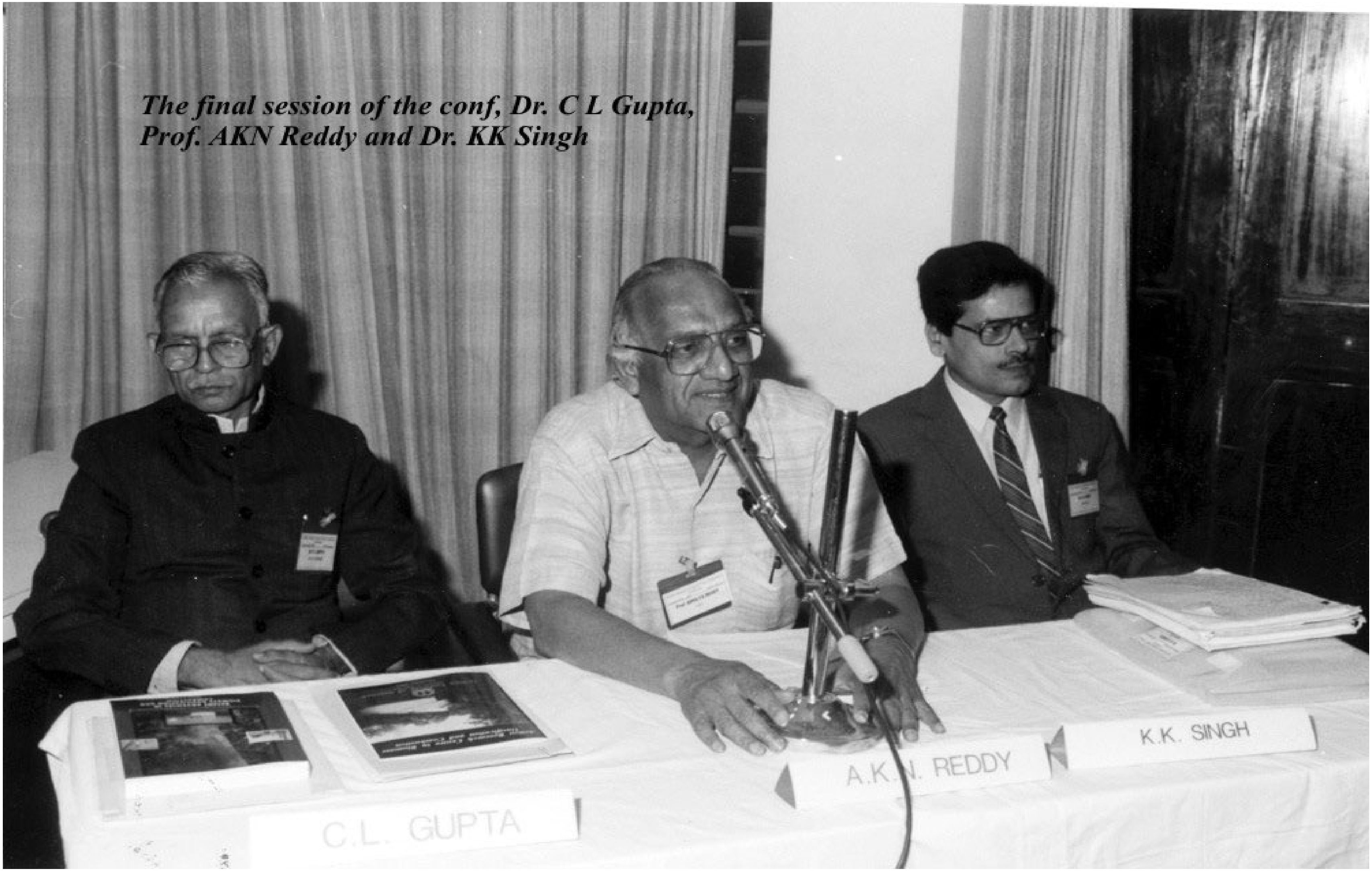
16.4. The moon mission

Later, during the tenure of Dr. K. Kasturirangan as the Chairman, there appeared a news item that ISRO was exploring exploration of moon, with first a landing of a spacecraft on moon. By this time, Dr. P. Goel who was the director of ISAC (ISRO SAtellite Centre) had organized a conference on low-cost access to space and he had invited me to make a presentation on this subject. It was also a time when Dr. Abdul Kalām along with Mr. P. Venugopalan and another scientist named Gollakotta had presented a paper at the international Society of Airbreathing engines conference a few years earlier. I read through the international efforts on the subject, the pros and cons of the efforts and put together a paper on low-cost access to space and presented this at the conference. I firmly believed then and now that the efforts of low-cost access to space must address the launch of satellites to low-earth orbit (100 to 200 km altitude). In any case, I had enthused a few colleagues to look at an option of the space flight operations being similar to aircraft operations so that even tourists can avail of this safe and low-cost access to space with the space vehicle taking off like an aircraft, reaching a high enough altitude to initiate rocket engines to fly out of the atmosphere go in to space. Return through the atmosphere by appropriate re-entry procedures and land back finally as an aircraft (much like the currently abandoned space shuttle). A scientific paper on this subject was produced and stands published in the journal Astronautica Acta.

N. Jayan, K.S. Bijukumar, A K Gupta, A K. Kashyap, K. Venkataraman, J. Mathew, H S Mukunda, Studies on an aerial propellant transfer space plane, Acta Astronatutica, 54, pp 519 -526, 2004

Returning to the subject of what happened on the moon mission as it was called, I tried on one occasion, when I ran into Dr. Kasturirangan at Bangalore airport (at that time, the airport was at HAL) to speak to him that I had some thoughts on the subject of moon mission that I read in the newspapers and would like to discuss with him. He nodded briefly (did not clearly know if he said yes or a qualified no) and moved on. Nothing happened for the next several months and I lost track of the subject. One fine day I got a call on my landline at the office from a journalist-author-of-books (Weapons of Peace was in the draft stage because he came back to me to speak about my interactions with Dr. Kalām at the laboratory at IISc a few weeks later), Raj Chengappa asking if he could talk to me on the telephone on the subject of moon mission. This conversation appeared to me as a casual one asking for my general views. I indicated that it is stupid to do what USA has already accomplished twenty years ago again now and there are more significant missions to be on the cards. He came back a few days later wanted to have some pictures taken of me against a rocket engine background (we had and have the actual hardware of Prithvi liquid engine at the laboratory). I complied with these without much thought as was involved in some serious technical discussions on a biomass related project at that time. A few weeks later appeared an article in India today presenting me in the backdrop of the engine and Prof. N. Kumar, director of RRI and a well-known physicist who also belonged to IISc physics department and whom I had and have regarded highly. I was shown as disapproving the moon mission with strong words and him approving it as one of value. It appeared that I was a tool for this bizarre incident and surely, I could not walk back.

This led to many people cheering me on what I had spoken and several senior people who thought I had put foot into my mouth! Even these people were in agreement when we met privately or in circumstances different from aerospace interactions. For instance, I was at that time a council member of the then formed national institute of renewable energy (NIRE) with {Prof. S. P. Sukhatma and other distinguished members) and Prof. A. Ramachandran as the chairman. During the lunch time at this meeting, I was warmly greeted for being brave (or just showed too much of bravery also may have been a thought). For next couple of years, I was not invited to any meeting on propulsion at the Vikram Sarabhai Space Centre, Trivandrum. Slowly there was change. Chairmen changed and directors changed, but my linkage with working scientists continued to be a dominant feature when several of them were writing to me on e-mail several aspects needing some inputs from me. One of the major projects on hypersonic flight vehicle test that was long overdue and I was invited for the technical review in 2015. Beyond this point, I have been treated warmly in the same way as I was treated long ago.



The final session of the conf, Dr. C L Gupta,
Prof. AKN Reddy and Dr. KK Singh

INTROSPECTIVE CONVERSATIONS

17.1. Long conversation after an invited talk

Back in 2010, I gave an invited talk to a group of teachers and researchers in Bangalore generally along the lines I have stated with illustrations from my career. Subsequent to this talk, one of the participants who was writing to a daily newspaper wanted to speak to me in some detail. We sat in one of the side rooms and the conversation went on for about 45 minutes.

Q: I missed some key points you made in your talk. Can you summarize them to me?

A: Please understand that in a classical educational institution, say a science or engineering college, there is a schedule for teaching, as well as class examinations and final examination. The role of the teacher is clear cut. Teaching and examinations occupy their time.

It is vastly different in institutions like IISc. Teaching has relevance. Teaching is composed of traditional topics as well those in which the particular faculty has special new knowledge. Good teaching has rewards of attracting bright students towards research. Teaching without research does not allow for healthy, respectful, and warm view amongst colleagues, a feature very essential to make academic living worthwhile. Attracting research grants is also an important element in a successful academic career because the outreach of a faculty member to do something significant nationally or even internationally.

Q: Is this situation uniform across the science and engineering groups within the institution?

A: Not so. In science departments, teaching is considered secondary and treated so. Research and publications in international journals are considered very important. Curiously, this leads to the choice of problems and conduct of research that is practiced at the current time by their international peers. Following the pathways and getting appreciation from the international peers becomes more important than creating new native pathways for the choice and resolution of problems. Of course, there are and will be exceptions. Successful exceptions are very rare.

In engineering departments, your value to the native society, may be for research and development organizations like DRDO, ISRO and some PSUs, or other industries or for rural demands is also an important measure. This value is to be derived from the choice of fundamental research problems that should have greater local significance or conducting research at both levels - national and international. This may sound crazy, but hopefully, I will illustrate to you these ideas with some examples. Thus, an engineering scientist in an advanced institution has to be visibly present at three levels - international science to derive respect from colleagues in science departments, science relevant to national needs to derive respect from scientists in national research and development institutions (like CSIR, DRDO and ISRO for instance), technology development to serve the larger industrial demands of the nation apart from teaching which is a primary ingredient for survival.

The larger segment of the Indian society is far more respectful of an Indian Nobel Laureate than an important contributor to the societal needs. An excellent example is related to Sir C. V. Raman and Sir M. Visveswaraya - you will recognize that Sir C. V. Raman is far more known. It is also true that Sir M. Visveswaraya is far better recognized than say Homi Bhabha or other physicists who did not attain the holy grail of being a Nobel Laureate. Thus, the issue of what to do to be visibly connected to the society is a complex matter. There can be many hues of views.

Q: You have spoken about international relevance. What is the work you have done that is internationally relevant? Has it even been recognized as your contribution?

A: There is scientific work that has been internationally relevant. There is also technological segment that is internationally relevant. Recognitions have been there through invitations to speak at specific important conferences, to provide training sessions on the science and technology aspects and give lectures from academic institutions.....

Q: Tell me about your scientific work.

Till about the end of nineteen eighties, a debate that was reigning in combustion was whether premixed flames (fuel gas like natural gas and gaseous oxidizer, like air) have a fundamental lower limit of propagation because there has been an experimentally limit and the key question is what should this be ascribed to - experimental features or whether there is a chemistry dependent fundamental limit. The work was carried out by Prof. Lakshmisha when he was a research student at IISc with Prof. P. J. Paul and myself as supervisors. An accurate numerical calculation with realistic complex chemistry revealed that the flame could propagate at speeds much lower than the observed limits. This created a positive wave in the subject at that time. Work was also further completed to predict the limits themselves considering experimental features. You must appreciate this work has no application value. Its value is to clarify a certain fundamental behavior.

Q: ....No scientific studies that are "useful"?

There are in fact scientific studies with immense application value. Let me illustrate one from aerospace field and one from biomass related field.

There is a phenomenon called erosive burning in solid propellant rockets. In solid rockets used in defense applications, one needs to load the rocket motor as much as is possible (a feature called achieving high loading density).

Such arrangement with tubular grains causes velocities of the hot gases through the tube to be so high that the burning of the propellant is influenced by the high velocities. There was much work - experimental and “modelling” work on this subject including one that I myself contributed to in 1983....

Q: Can I interrupt.... What do you mean by modelling?

Modelling means that you consider the principal parameters that affect the phenomenon and set a relationship through insight into which parameter has greater influence and which has less, etc. This process is helped by the use of dimensionless numbers - if there are two length scales in a given problem, then what governs the behaviour is the ratio between the two. Similarly, if length and time are involved, there will be a fundamental feature involving velocity (or rate of diffusion, etc) and what will matter is the time divided by a time scale that is obtained by dividing the length by the velocity. In some problems you may have many dimensionless numbers or you can conceive of several of them, but it is only a few of them that may matter. In this problem as well, several distinguished scientists from many countries had tried their hand at the problem and made the problem extremely complex - the joke was that if simplifications are done, they may be out of job!

Well, this was what was done at IISc. I looked at the experimental data from all the published sources and the data bank was not small - ten laboratories over six countries and about twelve solid propellants of different compositions over a range of pressures and velocities across the surface of the burning propellant. There was a total of over four hundred data sets. Invoking a hypothesis that chemistry does not control the enhanced burn rate due to flow of hot gases across the propellant surface an important fundamental dimensionless parameter was chosen to correlate the data into a simple single expression with no demand for free or adjustable constants. In order to verify if such an expression was indeed correct, data set from highly loaded propellant system was drawn and compared against. The latter effort was undertaken by my colleague Prof. P. J. Paul. This work published after considerable display of unfair practices from an established journal led finally to its acceptance at another important journal. The correlation is used for the design of highly loaded rocket motors in defence laboratories. Since there are no free constants, many are “unhappy” because, they cannot do anything further on the subject except some occasional noises. It is like the last word has been said on the subject.

Q: Last word in engineering science - how is that?

The data set that is incorporated in the correlation is large. There is scatter in the data and some recent researchers may think they will do more accurate experiments. But the procedure to extract the erosive burning data from the experiments is tough and the established data from two different researchers of repute producing data on the same propellant show differences that contribute to scatter. Thus, any brave new person will need to do sufficiently large number of experiments over a range of conditions and show that the current data set is inadequate. In reality, such a situation will not arise. Let us remember that this work is of value to a select group of solid propellant engineering scientists and is not of any significance outside of this group. It is very far from the subject like the measurement of the velocity of light, for instance, that is of great significance to science all round!

Q: All right. You have provided the example from aerospace field. You said you had something important in biomass field.

Yeah, there are several new discoveries in the biomass field, but I will now restrict to one significant development. It concerns biomass gasifier development for electricity generation purposes. Much history on this is recorded in a book [You can see it in Clean energy and fuels from biomass in www.hsmukunda.in] and I will touch only on the salient points. Most work on gasifiers followed the closed top design European WW II experience in India and other south east Asian countries. A departure was made by Thomas Reed from the USA using an open top design. Both these designs generated reasonably good quality gas when the biomass feed stock was rightly sized and was dry, but produced tar unacceptable to a turbo-supercharged spark ignition engine because of the production of of tar. A design with staged air injection was the development of IISc and was far more robust than other designs in providing excellent quality gas over arrange of throughputs. Its benefits, it was argued and demonstrated in experiments that the staged air supply will enable burning away tars produced above the air nozzles and allow the oxidized products to be reduced to combustible gas downstream. These were published in refereed journals. This technology was tested later (in 1994-1995) thoroughly by Swiss scientists both in India and in Switzerland and became a benchmark in biomass gasification technology in many countries of significance - Switzerland, USA, and Japan all of which received technology transfer and Brazil, Uganda, Chile, and Thailand where the technology was installed. Several invited talks in Stuttgart in Germany, Rio de Janeiro in Brazil and Bangkok in Thailand followed.

What was done was a science-based technology development that later was sought after by the most distinguished partners in different countries. Systems using this technology were built in India and overseas over a period of time. Scientists and practitioners from different countries were trained at IISc during the period between 1996 to 1999.

Q: Are there systems in service now? Can I see some?

There may be some systems in service more for ultra-clean thermal applications at throughputs up to 200 kg/h. The introduction of solar photovoltaic power generation systems with substantial Government subsidy led to demise of biomass based renewable energy technology and most industries involved in power generation have switched over to solar energy-based electricity. Even the thermal systems have a competition from natural gas supplies to industries. When this happens, the ease of availability can outweigh the simple economics of operation of biomass based systems.

Q: Does it mean biomass is unlikely to be used as an energy source? I am asking this because smoke belching cook stoves are used in villages even now.

Yes, indeed. Between 1975 and 2005, the enthusiasm to obtain electricity from biomass was very high. There were several programs of the Ministry of New and Renewable Sources of Energy (MNRE) that encouraged use of biomass both for electricity and heat. We did a large number of scientific studies, technology development, field testing, technology transfer, and technology support during this period. Improved cook stoves program ran for about forty years in various forms. Both these programs have been phased out. Rural cooking has been galvanized by the free supply of LPG cook stoves and a cylinder. Refills have to be paid for. This program has run a roller coaster ride because many rural households do not earn enough to obtain refill nearly every month when they need it. Thus, a fair fraction still cooks on old stoves that are smoky. There is no possibility of entry to advanced cook stoves (that are emission friendly in addition to being efficient) since the first cost will not be paid for. The summary is this. Biomass for electricity is not to be pursued any more. Biomass for cooking can be dealt with for larger applications including hospitality industry where the cost of fossil fuel is high and there is genuine interest in reducing fuel costs.

Q: Does all this mean that biomass sector for energy is doomed?

No. It has made it challenging. Unfortunately, it has been remained challenging over the last forty years by various Governmental regulations and uncorrected public perceptions.

Q: How come, Governmental regulations?

Let me take a starkly vivid example. Take the case of urban solid waste. Lots of studies on the composition of waste were made and great justification for bio-waste to energy were projected in this period. This subject was and is important since no sustainable solutions have been implemented over the last forty years. At one time, waste to electricity dominated the scene. Projects after projects via biochemical and thermochemical conversion routes with substantive capital subsidy were allowed to be implemented by private entrepreneurs. About a few hundred crores were spent in major cities - New Delhi, Mumbai, Lucknow, Bangalore, Chennai, Hyderabad, Trivandrum, Pune and other cities. You will see that almost every project has shut shop in a few years, many of them even before they were completely built. The key failure in nearly every project has been to produce electricity from biomass. The projected investment cost was nearly double of a project on electricity generation from supplied fuel - coal or biomass because the pretreatment processes were elaborate even after ignoring the need to keep the surroundings unaffected. Further, the cost of electricity generated was set to be absorbed in the grid with tariffs paid at values similar to those from other sources and lower than the production cost from this source in most cases. The urban municipal bodies in many cases were not rich enough to own up the projects either. Lots of lip sympathies from MNRE, Ministry of urban development and no sensitive effective solution.

If we remember that finally a large fraction of the urban solid waste is biomass, you will see what kind of challenge the society is posing for itself and the Government has rarely moved with the needed sensitivity even as of now!

Q: Over your life, has there been any scientific development that you have considered outstanding?

Yes, indeed. There is a mode of combustion called “flameless combustion”. The word flameless implies that the flame is transparent. We can get such a flame generally only for hydrogen-air mixtures because the flame does not have any species which give bright illumination. The bright illumination comes from partially oxidized fine carbon related compounds. In the flameless combustion mode that I think was invented in Germany, the gaseous fuel and oxidiser are injected separately into the combustion system at large velocities (even up to hundreds of m/s). These separated jets get mixed with the products of combustion that are "entrained" because the high velocity fuel and oxidiser jets create a low pressure just around themselves. The fuel and oxidiser jets get heated as well as diluted as they move into the combustion chamber. At a station where the temperatures cross the "ignition temperature", the they react and release heat. Because the mixtures are dilute and yet at high temperature, and the heat release process occurs fast, one gets a mode of combustion that is nearly transparent. Even after knowing the principles above, I would definitely say, I would not have invented it unless serendipity played a role. Therefore, I have great admiration for this mode of combustion that Prof. Sudarshan Kumar (presently at IIT Bombay) spent time introducing scientific tools to characterise the system as a apart of his Ph.D at IISc. This approach to combustion has not received as much attention from scientists in the USA partly because it is not one of theirs (perhaps)!

Serendipity did play a role in its own way for me. I was once asked to develop a horizontal combustion device for solid fuels like firewood and pellets for an application in sand drying for a foundry industry. I was playing around with a geometry in which the volatiles from the biomass were generated by the heat transfer from the flame and part air flow through the bed of fuel. The gaseous fuel was to be burnt with air. This air was supplied using fine jets of 5 to 20 mm diameter. When the air flow was turned on at full blast, the combustion process became delightfully transparent! It appeared so beautiful that I kept staring at it for a long time - even now, when I see such flames, I feel “fulfilled”. Well, this became the bed rock of the new technology called horizontal continuous clean combustion device - HC^{3}D - that has been built from domestic to industrial level combustion systems.

17.2. A casual but penetrating conversation

It was in IIT Bombay on the 14 February 2020. I was there for the 6th PJP memorial conference (14th and 15th February, 2020). During the evening I met a few colleagues, some of them younger than me. We talked about old times, friends we knew and those who were no more around. After a while, someone asked a question - have we done something worthwhile other than publishing and publishing and publishing. In our profiles we proclaim a number against our publications, expect the hosts to announce them when we are invited to attend to inaugurate or provide a key note speech. This led to the related question by my younger colleague: What is it you (meaning the seniors) have done that is significant? What has been done that outlives us and has significance to the society, scientific as well other groups. After a pause allowing each one to dwell in one’s own thoughts, the persistent young man looked at me quizzically and said that he had read a few documents arising out of our laboratory that he had visited in 2000 and one document “Troubling questions and beyond naive answers”. I said: interesting....so. He said: On occasions you have indicated that you are looking at Swargarohana parva.....(of MahaaBhaaratha). Without emphasizing why, I am asking you, and before I ask others, can you first let me know the meaning and relevance of your scientific work in the sense we have spoken a little earlier. I had to collect my thoughts and said that whatever I wrote in my publications and other writings, it was done because there was at least one significant and new idea. Except in the first few years during which period, I must declare I followed up on important people in the field and uncovered what work they were doing was significant and took a similar track. But soon enough, I had to expand my idea of "significant" to include what I could do of significance in science and technology of relevance to India and also wistfully thought some from overseas must come and learn from us (somewhat like in old times of Takshashila and Nalanda!) and expressed these to a bit of weird look from some of my close friends!

Amongst the hundred odd publications in peer reviewed journals (not large by standards of this day!), about six of them are perhaps very insignificant, two of which I revisited and led to the whole new way of thinking. I will relate them now since both these have had a very significant outreach into design in of propellants in defense and space laboratories. In 1983, my thinking was that chemistry was a key contributing factor in a phenomenon called erosive burning in solid rocket propellants and constructed a theory to support it and some data to validate it. In 1997, lot more data was available and a consideration of these data showed that fluid mechanics was appropriate and adequate to explain all the data and a simple dimensionless correlation that had no free constants explained the data within the error band. This equation has been named Mukunda-Paul model in defence circles and has been used for over 20 years in DRDO for the design of highly loaded solid propellant grains for missiles. Some discrepancies of predictions using this model were brought to my attention sometime in 2013 and these were addressed in a computationally intensive work along with scientists from DRDL and again, fortunately, a simple way to estimate a characteristic length was adequate to make the predictions appropriate in non-axisymmetric propellant grains was found. The second subject is related to burn rate modelling of composite solid propellants (discussed in chapter 14)

One of my other colleagues interrupted and reminded me that these are in an exotic area, enquired if there was something that touches the broader world. I will relate to you two aspects on research and development of gasification and clean combustion of biomass, an area I have spent about forty years and am even now active in a serious way. In the first twenty years, building on earlier knowledge, we (the team involved Dr. S Dasappa, Dr. N. K. S. Rajan. Prof. P. J. Paul, Dr. U. Shrinivasa and myself over the initial period of 10 years) developed new science-based technologies for gasification and electricity generation. These were demonstrated to large teams national and international with a dozen patents in various countries. Technology transfer to several industries in India, an industry in Japan, to Switzerland via their industry in India and after my withdrawal from IISc in 2003, to GE (USA) in 2007. US (GE) met with the Director IISc and stated to him that they are coming to IISc because in their review of the work World over, this was the best technology. More than a hundred systems of various capacities for electricity generation and clean heat were built over this period. During this period, the number of scientists, technologists and users who visited the laboratory is very large and there were training workshops for scientists from the USA, Europe, Brazil, Africa, South east Asia, and I acted as an FAO specialist on biomass conversion technologies to conduct workshops in Indonesia, Thailand and mainland China. All distinguished visitors to IISc were sent by the director's office to visit the laboratory. In some ways my thinking that we should act as a learning center for the World was fulfilled.

It was only in 2010 that solar photovoltaics as an economic power generation system with extraordinary subsidies both on capital as well for electricity generated upset the balance in favor of it much against all other approaches for alternate power generation. My own assessment showed that the entire bit of biomass for electricity was doomed to disappear in some years and this turned out to be correct. The same technology was adopted to produce clean hydrogen from Biomass by Prof. S. Dasappa in recent times by using steam and oxygen as the reactants. Thus, the variants of technology are being moved forward. This class of technology can work only at large scales and other approaches for biomass utilization must be pursued. This is due to the fact that approximately half the World still lives on cooking fires that use biomass and charcoal in a way that the undesirable emissions are much above acceptable standards. While I was always thinking of the science of biomass combustion all the time when we were pursuing gasification technologies, it became more focused in the period beyond 2003. One class of technologies based on reverse down-draft technology used for gasification (also known as top-lit updraft mode) was pursued in great depth in a Ph. D thesis of Varun Shivakumar and additional inputs on the technology transferred to British Petroleum India Limited were provided. Even during his pursuit of Ph. D, the design methodology that came out of his work was transferred to them. Many were the challenges beyond science that were pursued jointly. This technology was of fixed biomass and moderately variable duration. During the later stages of the semi-commercial exploitation of technology to over four hundred thousand households, the need for a continuous combustion device was expressed. Much research went into this and finally two configurations, namely HC^{3}D (horizontal continuous clean combustion device) and VEBCOD (vertical ejector induced biomass combustion device) were evolved, investigated with regard to the process details, published, technology patented and transferred to several private industries. At this time, systems large and small are being built for the hospitality and other industries with the aim of reducing the fuel costs while limiting the emissions to standards. This whole saga on biomass-based combustion technologies will last at least for one more generation until the World abandons biomass for combustion applications. Such a situation will not arise at least in my life time! You might ask me: Are you unhappy that you did so much for biomass gasification technologies and now it is no longer in vogue? My answer is that we do the best we can during the period we can. Things need not remain the same all the time and I am inclined to repeat Bhirtrihari's words: Chakaara panktiriva gachchathi bhaagyapanktihi. Good period moves like the wheel going up and down in its movement. In any case, no one of us lasts very long and if we become a tool for transfer of "knowhow" and "understanding" to the next generation, we can pursue the path of Swargarohana....!

MY ASSOCIATES

18.1. The students, studentship and after

18.1.1. ME students

There are three classes of students in postgraduate institutions, like IISc. The students who take course on a subject because it is a core course compulsory for getting the master's degree. This number is equal to the number of students joining to get a master's degree, typically between 25 to 40 at the department of Aerospace Engineering. Amongst these about a third to a quarter will take special courses in a special area – structures, aerodynamics, combustion/propulsion, and guidance and control will in addition take some courses in the respective areas. All these are of one class. The students then have to undertake a research project in the specific field with a specific faculty member. These ME projects will get distributed amongst the faculty variously depending on the year and the nature of students. Over the thirty years I must have handled more than fifty students, more in the early years than in later years. This is because, I did not have any research student for some time and I would engage with ME students very intensely. Slowly, the number of research students and the research projects that were taken up needed more time and I wound not put in any special effort to attract ME students. In the early years when the rockets and missiles course became popular, one got a good crop of students, partly because they were assured of a job after the course was successfully completed. Amongst several of the students, a few of them stand out. B. V. Gupta, A. Subhananda Rao, S. Sambashiva Rao and Sankara Rao. All these students joined DRDL after the course. Gupta worked in the solid propellants group for about six years and left DRDL to pursue his family business in Rajasthan. Others continued in DRDO with Subhananda Rao becoming the Director of HEMRL subsequently and then Director, GTRE and then Director General (aero). Sambashiva Rao and Sankara Rao completed their career in DRDL and retired from service. The difference between the three Rao's was that Subhananda Rao was always vigorous, active and dynamic and climbed higher in authority consistent with his intellectual ability as well. There were several others like Wing Cdr A R Vaidya (who later became AVM Vaidya) who went to DRDO and CRE aircraft and Airforce depots and other agencies and brought back to me interesting practical problems of significance. Some of them led to serious pursuit of research like in the case of erosive burning in solid propellants. One from Airforce depot brought a problem of flame extinguishment in some manoeuvres of Mirage 2000. This could not be pursued beyond a point because Airforce did not want to release any data on these.

18.2. Research students

More than twenty students got their Ph. D with me as a supervisor and other co-supervisors. Nearly every Ph. D student did a different problem.

Several in (a) gas phase combustion - A T Bhashyam, N. K. S. Rajan, K. N. Lakshmisha, Gajendra Goel, D. P. Mishra, Sudarshan Kumar, (b) liquid droplets polymer droplets - B. N. Raghunandan, (c) Hybrid rocket fuel burn rate - P. J. Paul, (d) Rocket side injection thrust vector control problem - Raman Balu, (e) Supersonic combustion processes - Debasis Chakraborty, (e) Solid propellants - H. K. Narahari, P. A. Ramakrishna, (f) Biomass gasifier related - S. Dasappa, G. Sridhar and (g) distillery effluent waste N. M. Patel, (h) Biomass stove related - Sangeeta Kohli, Bhaskar Dixit and Varn Shivakumar, and (i) fire related - Sowrirajan and Shiva kumar

Two students of Prof. P. J. Paul, Arvind Iyer and Abhishek Bhat had spent years and had not brought the work to a stage when it could be thought worthy of being put together into a thesis after the untimely passing away of Prof. P J Paul (honestly and regrettably, they would have not completed their theses in the way things were for several more years). Much (more) effort had to go into shaping the work with additional work into theses worthy of IISc. Much less effort went in the case of Biju Kumar to shape the work into a good thesis.

Varun Shivakumar who was formally the student of Dr. N. K. S. Rajan spent a large time with me on the biomass stove combustion problem in 2009 much after my retirement. Sowrirajan, V was registered in Jain university with Prof. Dixit and myself supported his research completed in 2013. Similarly, Mr. A Shivakumar registered with Prof. Dixit and myself has completed his Ph. D.

The work towards the theses of the students involved experiments, modeling, analysis and computational approaches. Gas phase chemistry was considered of interest for about ten years and several theses were devoted to this area. Subsequent work was in different fields discussed above. In what I will describe below, I will set out one important scientific finding of each of the theses briefly

My first research student was Mr. B. N. Raghunandan (BNR) who joined the department in 1970 after his B. Tech from IIT Bombay. The problem that was considered for the research was liquid and polymer droplet combustion. At that time, the problem was a hot topic and was being pursued by several scientists - Dr. C. K. Law, Prof. Forman Williams, from the USA, Prof. Kumagai and Satoshi Okajima from Japan amongst others who were doing remarkable zero-g droplet combustion experiments. The research study produced a very significant finding - the large difference between the observed flame-to-drop diameter ratio and that predicted by simple theory could be brought close to the experimental finding by a more rigorous treatment that accounted for thermo-physical property variation through the diffusion flame. Unfortunately, this result published in a reputed journal, combustion and flame - continues to be ignored over the past forty years - even to an extent that a book published in the late nineties presents the difference as an issue that can remain ignored! He finished his Ph. D, got recruited as a faculty member in the department of Aerospace engineering at IISc itself and continued his career in combustion science and held several senior administrative positions at IISc.

P. J. Paul was the next student. He was doing his M. E in chemical engineering department and has a research project with Prof. V. G. Kuber in 1970. I was called in as a project examiner. I was impressed with what he did (despite Kuber!) and more impressed when he indicated honestly that he did not know the answer to a question on what he had presented. A little afterwards, I spoke to him and indicated that he could join us on a project related to hybrid rocket engine development, if he liked. He joined the project and later through a due process became a research student between myself and Prof. V. K Jain as the supervisors. His research on the regression rate of hybrids clarified a major issue bugging the field. A relatively simple theory due to Marxman and Wooldridge implied that the regression rate has little dependence on the nature of the fuel. Experiments performed with natural rubber and oxygen showed that the regression rate had a much larger dependence on the nature of the fuel than what the theory indicated. To explain this, the theory of heat transfer from turbulent flame was modified to include the pyrolysis of heavy fuel fragments into the gaseous stream was shown to explain the observed behavior. This result was also justified by comparison of experimental data on injection of heavy gases like CO2 into a turbulent air stream by Academician Dr. Kutataladze in his book on heat transfer (I visited him and his institution in Siberian Academy in 1982 with a delegation and discussed in chapter 12). Dr. P. J. Paul became a faculty member in the Aerospace Engineering department and he was a co-supervisor for most students who joined afterwards and participated in most research and development activities on aerospace and biomass. He was the review committee member for many developments in DRDO and ISRO. He continued as a professor till his untimely death in 2012.

H. K. Narahari joined as a research student around 1982 and studied the problem of burn rate of Ammonium perchlorate with complex gas phase chemistry. The work was performed because the pressure index of the burn rate was lower than 1 and it was then thought that some first order chemical reaction steps must be responsible. The paper was accepted for the presentation at the 1984 international symposium on combustion at University of Michigan. Narahari got his Ph. D working on the details of this problem largely devoted to gas phase chemistry. In later years, the role of such a complex chemistry was abandoned in favor of a burn rate model that worked well with a simple chemistry to predict burn rate vs. pressure and initial temperature. He completed his Ph. D, worked at the Aeronautical Development Agency (responsible for the design and development of the light combat aircraft), left it and after several other jobs became a faculty member at the M. S. Ramaiah Institute of Advanced studies.

A. T. Bhashyam became a student in 1981 under quality improvement program in which engineering college teachers could be deputed to earn their Ph. D in institutions of higher learning. He was my engineering college classmate and subsequent to B. E., he joined as a lecturer in an engineering college and after about ten years decided to earn a Ph. D. His problem was chosen as an operator split procedure for the solution of premixed flame propagation problems with Prof. S. M. Deshpande and Prof. M. R. Ananthasayanam as the other supervisors. He had a warm personality and worked hard to get through his work and get his degree. He returned to Jayachamajendra college of engineering and continued his academic work till superannuation.

N. K. S. Rajan had joined the department in the hybrid rocket motor project in 1977. Initially he was working away at computerized data acquisition to the laboratory from the enclosed rocket test stand about 30 m away. Sometime in 1980, the project on building high velocity burners based on LPG was begun to help stress relieve large storage and reaction vessels (10 to 20 m dia spherical vessels). Consequent upon this several projects in Mathura refineries (Mathura), Rourkela steel industry, Kalyani refineries (West Bengal), Cochin Refineries were dealt with. M/s Cauvery industries, Trichy were the industry involved in building the vessels and the stress relieving operation was to be done as per ASTM standards. While the story of how this came about is worth a separate description, the key scientific problem that became the subject of Ph. D of NKSR arose from what was done was how was the heat transfer from the hot gases to the wall was taking place - radiation, convection and their relative magnitudes in actual systems. More description of this appears in chapter 8, section 8.3.

K. N. Lakshmisha joined as a student (between P. J. Paul and myself) and began his work on premixed flame modelling to specially examine the behavior near flammability limits. As indicated earlier, this work had special significance in resolving a confusion in the literature - as to whether the flammability limits had a fundamental chemical origin. What got demonstrated clearly was that such a fundamental limit does not exist. This was possible because the code developed was based on unsteady formalism and allowed the capture of very weak flames through successive grid refinement. He went abroad for his post-doctoral work, returned and became a faculty member in IIT Kanpur first and later joined IISc Aerospace engineering department where he is continuing to work as a professor.

Around this time, Gajendra Goel joined as a research student (between S. M. Deshpande, M. R. Ananthasayanam, P. J Paul and myself) and his problem was also one-dimensional premixed flames using the code to make calculations of specific flames - connected with oxides of nitrogen. He did some specific numerical explorations of converting an explicit numerical code to implicit format to increase the numerical stability also. Subsequent to his Ph. D he went on to do his post-doctoral work in Germany and sought employment in Canada. He has perhaps left the field and is not in touch with the laboratory.

S. Dasappa became a research student after he had joined ASTRA (Application of Science and Technology to Rural Areas), currently called CST (centre for sustainable technologies). His thesis was supervised by Prof. U. Shrinivasa formally with the mechanical engineering department also deeply associated with ASTRA (of which he became its chairman later), P. J. Paul and myself. His work was to create foundations of the gasification process. This included single particle conversion studies of char in atmospheres of oxygen-nitrogen, water vapor and carbon dioxide atmospheres, and propagation rates of biomass piece filled transparent glass (quartz) reactors amongst others. Much understanding of the gasification process occurred with his direct participation in earlier times. He also was active in troubleshooting gasification reactor related problems under many awkward field conditions and was not hesitant to take responsibility for these actions. He has worked on several projects related to energy over a time and continued at IISc is currently Professor working at CGPL, and as the chairman of the centre for energy research.

Raman Balu who was a scientist in the aerodynamic division of Vikram Sarabhai Space Centre (VSSC), Trivandrum wanted to pursue his Ph. D through the external registration program of IISc. He joined sometime during 1980. He was the joint student of P. J. Paul and myself. His work was on the problem of the computational study of liquid injection thrust vector control used on the 1st (and 0th) stage satellite launch vehicles. There were test stand based experimental data on the side thrust produced when various amounts of liquid (strontium perchlorate solution) were injected. The flow field with strong shocks was to be captured in an otherwise axisymmetric nozzle and side force evaluated using the asymmetric wall pressure field. He completed his Ph. D and continued his career at VSSC till his retirement. Subsequently, he has been teaching at an engineering college.

Sangeetha Kohli, a research student of Mechanical engineering department with Prof. J. Srinivasan wanted to have me as a supervisor since she was interested in working on stoves, sometimes in 1980. It was jointly figured out that free convective flow in a vertical hot tube (open at both ends, of course) was not resolved and a large part of the computational study was devoted to understanding free-convective flows through hot tubes. Of course, she did analyze the heat transfer tio the vessel on the top and finished her Ph. D. She has been with IIT Delhi as a Professor of Mechanical engineering all along.

G Sridhar (also termed S2 since we had several Sridhars at CGPL) came in as an employee of KSCST working on MNRE projects that were undertaken under KSCST. He participated in research and development of gasification and producer gas-based power generation systems. His thesis was supervised by P. J. Paul and myself. He constructed the models of the combustion processes inside the reciprocating engine cylinder, both one-dimensional and fluid flow processes including combustion of premixed producer gas-air mixture. In this manner, his work led to the completion of the foundations of producer gas power generation using reciprocating engines with modern open top re-burn gasification systems. He has written about his life in CGPL and beyond in Chapter 20.1.

D. P. Mishra joined the research group at CGPL after joining Prof. U. Shrinivasa as a research student in Mechanical engineering department. He was jointly supervised by P. J. Paul, U. Shrinivasa and myself. His work was related to stretch effects on one-dimensional flames. He solved the spherical flame propagation problem with thin flame approximation to extract the effect of curvature. Most data on stretch effects were consolidated and examined in this framework. He finished his Ph. D and went to become a faculty member in Kanpur and he moved on to head the teachers training institute in Kolkata in 2020.

Nikhil Patel joined as a research student and intended to work on development of ramjets, etc. After discussion, he settled down to studying the distillery effluent solid waste material for its effective disposal via combustion route. One very interesting scientific result has been that the solid material contains significant combustible material and its burn rate parallels liquid droplet combustion. He migrated to USA after his Ph. D and has his own start up in the USA.

Debasis Chakraborty working with the Aerodynamics division of VSSC joined as an external registrant in 1996-1997 period. P. J. Paul and I were his supervisors. His work was largely carried out with computational infrastructure at VSSC. He carried out a large number of computations and compared several results with some rare experiments carried out at that time. He finished his thesis, spent some time at VSSC before moving on to the CFD division at DRDL which he headed till retirement. Subsequently, he is heading Centre for Propulsion Technologies at IITB where he is also a professor in the department of Aerospace Engineering.

P. A. Ramakrishna joined as a research student after completing M. E. in the department in 1998. The problem he worked for his Ph. D was related to sandwich propellant combustion - with very thin slices of polymer sandwiched between thin slices of Ammonium perchlorate. He conducted some experiments of significance at low pressures to see how the flame propagation occurs and also performed computational studies on this geometry. One of the most important questions that he answered was related to the activation energy of pyrolysis of AP. It turns out that the computation becomes unstable (and non-converging) if the activation temperature of pyrolysis was beyond a certain value. Getting this result accepted in propellant community was a difficult task, but was accomplished. He did post-doctoral work in South Korea and later became a faculty member at the Aerospace Engineering department of IIT Madras where he is continuing as a professor. He has written about his life in CGPL and beyond in Chap 20.3.

Sudarshan kumar Vatsayan joined the laboratory after finishing his M. E from the same batch as Ramakrishna. The problem that he worked on was related to flameless combustion. This choice of the word is not simply semantics but related to the fact that the flame is nearly colourless when operated in a certain mode in which the products of combustion recirculate in a chamber into which fuel and oxidizer are injected separately without mixing. The mechanism of clean combustion here is related to the dilution of both fuel and oxidizer jets with hot products of combustion and this process leads to rise in temperature while the fraction of reactants comes down. At a particular temperature close to about 1000 - 1100 K, the entire mixture ignites and burns up to its near- adiabatic condition. Because the temperature traversed by the reactants during the heat release process is much smaller than under normal combustion situation, one gets lower emission of undesirable pollutants and the acoustic signature of the turbulent flame drops significantly. After completing his Ph. D, he did his post-doctoral work in Japan and became a faculty member at IITB where he is now the chairman of the department of Aerospace Engineering.

Bhaskar Dixit was a quality improvement program candidate from Bapuji Institute of Technology, Davanagere. He joined in 1998. He was working with the simulation of swirl burner and there were difficulties in the computational studies and so switched to an experimental study of pulverized solid fuel combustion system. He performed systematic experimental studies on sawdust-based combustion system and also made computational studies on the flame propagation inside the solid fuel bed. He finished his Ph. D and went back to his college. Subsequently, he spent some time at MS Ramaiah institute for Advanced Studies before joining Jain university as the director of Fire and Combustion Research Centre in 2010 where he continuing as its director.

Varun Shivakumar had joined as a research student with Dr. N. K. S. Rajan and had taken courses. He apparently had indicated that he would submit his thesis for M. Sc by research at IISc and would like to go abroad. At this time, I spoke to him and suggested that an interesting problem on stoves is awaiting solution and would he be interested in continuing his work on his Ph. D with me helping out the research during this period. He agreed and stayed on. He performed experimental and modeling studies of significance to fixed reverse downdraft class of pellet-like solid fuel clean combustion systems. He completed his Ph. D and soon went on to become a faculty member at IIT Ropar. Subsequently, he moved on to the mechanical engineering department of IIT Madras where he currently continues his academic work. During the period after his thesis submission and the time for other actions to take place, we spent time looking at unsteady acoustic phenomena in solid propellant rockets. He picked up on the subject that would become an important study area in the later years. He has written about his life in CGPL and beyond in chapter 20, section 20.4).

V. Sowrirajan was a student from Jain university to register for Ph. D in the area of fire chemistry and engineering (which later became Fire and combustion research Centre, FCRC). I was a co-supervisor with Prof. Dixit being the formal supervisor. He performed research studies on coatings for in-situ fire sensitive roofs usually of Styrofoam that were placed without any fire safety clearance in small institutions/organizations. His thesis was completed and he got his Ph. D and is continuing on as a faculty member in FCRC.

A. Shivakumar joined the staff of the Fire and Combustion Research Centre, Jain (deemed-to-be-university) sometime in 2016. His Ph. D thesis was on the burn rates in pool fires. He conducted for the first-time systematic burn rate studies on pool fires on pans of different materials with various fuels and generated an accurate correlation for mean burn flux and a model for the unsteady burn profiles that runs on MATLAB code.

LIFE IN PICTURES

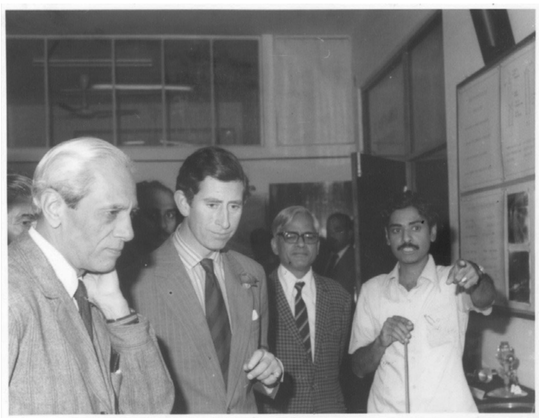


Photo 19.1 Picture taken during the visit of Prince Charles to IISc in 1971. From right: Prof. Dhawan, Director, IISc, Prince Charles, Prof. V. K. Jain, and I, Combustion and Propulsion group, Department of Aeronautical engineering; what is being shown is the model of hybrid rocket that was under development

Photo 19.2 Left: Prof. S. Okajima,, Japan and me taken near the dead sea, 1982 during the 19th symposium on combustion at Technion, Israel. Right: Prof. Okajima, I, another professor from Japan and Prof. A. G. Marathe, 1985 during the visit to his laboratory after the symposium at Tokyo

Photo 19.3 Top left: Dr. Abdul Kalam and Prof. I. G. Sarma signing the MoU, Dr. K. N. Swamy standing and me bending over; Top right: The director, Prof. S. Ramaseshan at the ground breaking ceremony, I am in the right end; bottom left: Prof. M. R. Ananthasayanam, me and Prof. S. Durvaula looking at the plan, 1983

Photo 19.4 Visiting Prof. K. Krishna Prasad at Eindhoven, Holland, on the return trip from the 20th symposium on combustion at Ann Arbor, Michigan, 1984; From left: H. K. Narahari, Nus, Myself, Prof. K. Krishna Prasad, Prof. U. Shrinivasa (behind) and Prof. B. N. Raghunandan

Photo 19.5 At the Eiffel Tower in Paris on the return tip from USA (combustion symposium at Michigan), 1984; Myself, Prof. U. Shrinivasa, Mr. P. Venugopalan (DRDL), Prof. P. J. Paul and Prof. B.N. Raghunandan

Photo 19.6 Answering questions after presentation at the Astronautical Society of India conference on liquid propulsion, Dr. S. Srinivasan, Project director, PSLV chairing the session, 1985

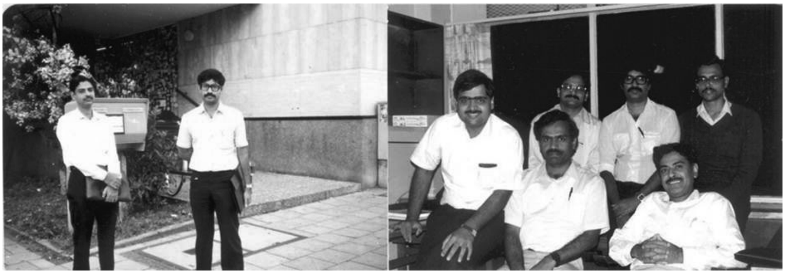


Photo 19.7 Left; Me and Prof. P. J Paul taking time off to see the Munich museum during the 21st symposium break in 1986; K. S. Srinivasan, B.N. Raghunandan, H. S. Mukunda in front row and Gajendra Goel, P. J. Paul and K. N. Lakshmisha in the row behind at the 22nd symposium, Washington Seattle,1988

Photo 19. 8 Left: Prof Narasimha and me in conversation at J N Tata Auditorium at IISc; right: Prof. Narasimha addressing the audience at the symposium with Prof U. R. Rao who was the chief guest and me, the organizing secretary sitting at the dais, 1992

Photo 19.9 Left: A 2 kg/h system connected to a Honda engine to deliver 1 kWe used in North Eastern India by Army, 2000; Right:The 750 kg/h system with the critical reactor design elements same as the 2 kg/h design, 2000

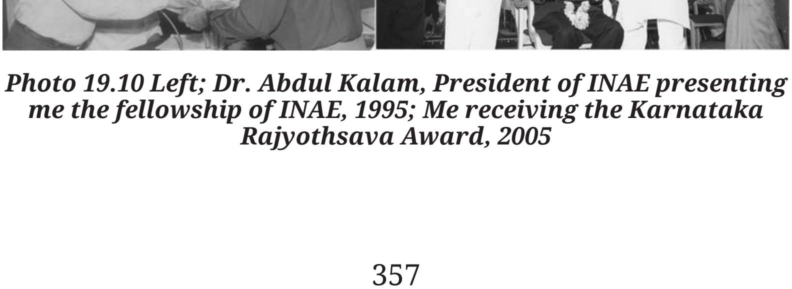


Photo 19.10 Left; Dr. Abdul Kalam, President of INAE presenting me the fellowship of INAE, 1995; Me receiving the Karnataka Rajyothsava Award, 2005

Photo 19.11 Left: Sir M. Visweswaraya award for sceince and technology, 2006 with Prof. C. N. R. Rao, the chairman of the selection committee and Prof. P. Balaram, director, IISc standing behind, Right. The distinguished alumnus award of IISc, 2004

Photo 19.12 Sitting from left: Wali, Gayathri, P. A. Ramakrishna, N. K. S. Rajan, H. S. Mukunda, P. J. Paul, S. Dasappa, G. Sridhar, H. V. Sridhar; Prof. Dasappa is currently taking care of the laboratory.

Photo 19.13 left: Along with the participants at the PJP memorial workshop organized by Prof. P. A. Ramakrishna in a beach resort hotel at Chennai, 2015; right: Responding to questions at the workshop.

Photo 19.14 The development of an ejector based horizontal clean combustion system, 2015

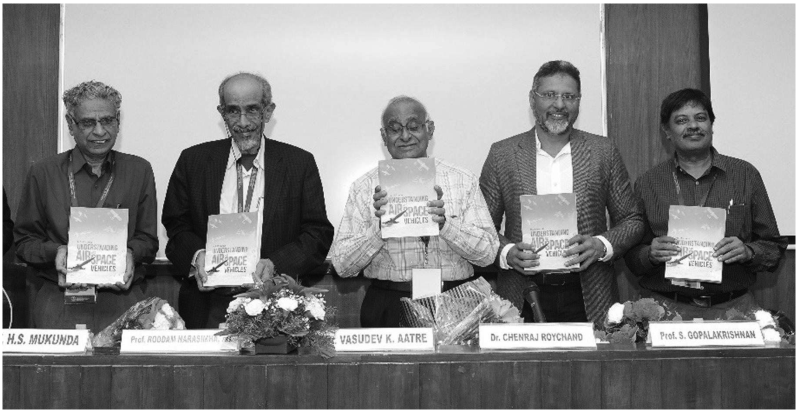


Photo 19.15 The book release function at the golden jubilee of the department of Aerospace Engineering; Me, Prof. Narasimha, Dr. V. K. Atre, Dr. Chenraj Roychand and Prof. S. Gopala krishna

Photo 19.16 Lectures on fundamentals of biomass thermal conversion technologies at Kannur Engineering college in 2018

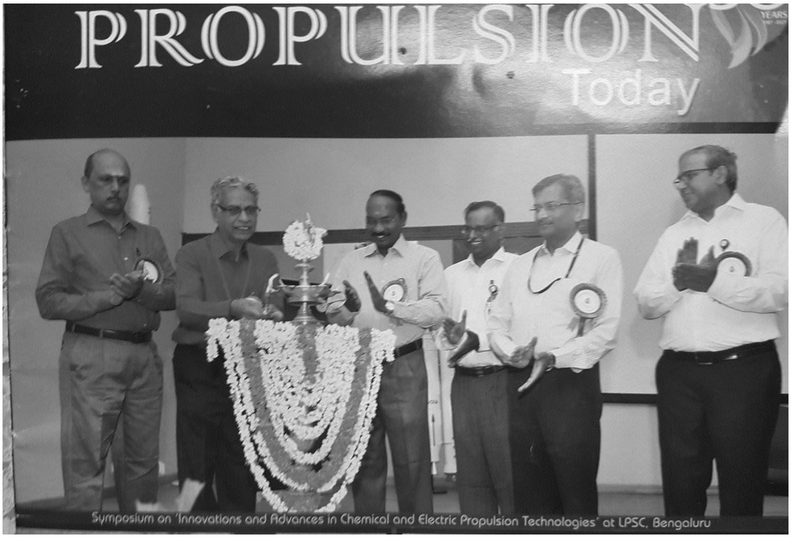


Photo 19.17 At the inauguration of a symposium at LPSC, Bangalore in 2019; Next to me on the right are Dr. Sivan, Chairman ISRO and Mr. V. Narayanan, Director, LPSC

MY CGPL

20.1. G. Sridhar

20.1.1, The early period

I joined CGPL, IISc as a Project Engineer in 1992 more as a stop gap arrangement because at that point of time I was keen to join industry. I was hired for a contract position of Project Engineer at Karnataka State Council for Science and Technology (KSCST), to work on an on-going research project at CGPL, with Prof H S Mukunda and Prof J Srinivasan (Dept of Mechanical Engineering, IISc) being the project principal investigators.

At CGPL, I got the opportunity to involve myself in several exploratory research activities and also contributing to the IISc-

Swiss gasifier testing program in 1993-94 as the Project manager. This provided me a huge learning opportunity as I was involved in the complete exercise of conceiving the test program, overseeing design and installation of gasifier system, prototyping of particulate and tar (P &T) sampling system and conducting of long duration trials as per protocol. The prototyping of P &T apparatus was pretty challenging. I vividly remember myself and Dasappa went scouting for glass jars, which led us to narrow streets on the Avenue Road in Bangalore. We had to deal with all kinds of strange questions from the vendors and finally the effort was worth as the apparatus was successfully fabricated, assembled and tested. We had to figure with our own pre-qualification norms/test procedures such that they succeed during the trials. Each test preparation was so involved that activity commenced at about 7 am in the morning and finished late in the evening by about 9 pm. Among the Swiss visitors, one Engineer by name Kaufmann was a bit sceptical about the entire test arrangement, so we had to be on toes to see to that all his queries are satisfactorily replied. Eventually as the test proceeded, he became friendly. The entire testing program seemed like a “festival in the lab”, which went on for nearly two weeks and all staff at CGPL got involved in one or the other activity and mingled with the Swiss scientists and Engineers. They too enjoyed our hospitality and relished Indian food!

20.1.2. Preparing for Swiss visit

The collaborative effort of IISc, India and DASAG, Switzerland took a further step in testing of one such gasifier system at Chatel-st.-denis, Switzerland during Nov 1995 - March 1996. A similar system to the one tested earlier was built and shipped in partly assembled condition from India. Packaging and shipment were a challenging exercise as all the components had to be fitted in a 20 feet container. Four of us from India - myself, Dasappa, Girish Belandur and Thirupataiah participated in these tests. Initially three of us reached the site for installation and conducted preliminary trials before the actual tests that were held in peak winter. We experienced many surprises; I would like to cite one that sounds funny – the original reactor design had a water seal at the bottom for ash/char collection. When we started installation of gasifier the winter was just setting in, we finished the work on a Friday by completing the gasifier leakage test, which involved filling the water seal container with water.

During weekend, the temperature had dropped sub-zero and the following Monday when we visited the site and about to start the trials, we realized that water had completely frozen in the water seal container! This is something no one anticipated including the locals! So, the Swiss project engineer Pasqule Giordano had to make arrangement of applying heating tape over the container to melt ice and also prevent water turning ice again! The tests were rigorous, and ETH also participated in the trials for measuring gas composition, P & T levels. The system was tested under adverse conditions (sub-zero temperatures) using different species of wood like casuarina, pine and green wood with moisture content varying from 12 to 30% at various loads. The duration of the tests varied from 7 to 9 h with tests carried at various throughputs. The P & T analysis was done by Cosmic, India and EMPA and Natura chemica of Switzerland. On the whole the outcome was positive allowing for minor variations in the some of the parameters. With respect our personal stay and living in Switzerland, we were comfortably housed in an apartment with a kitchen for preparing the Indian cuisine. I and Girish (G2) took turns in cooking, and made a point to carry Indian lunch daily during visit to the test site and also during weekends for site seeing. Our stay was of nearly 8 weeks, and during weekends we explored the scenic beauty of Switzerland, travelling by local trains, all by ourselves by using tourist maps! We had some fun time playing in snow at Lucerne.

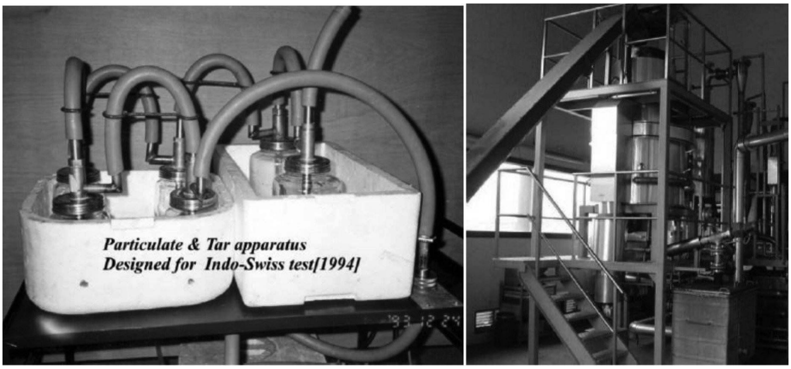


Photo 20.1 The IISc particulate and tar apparatus and the automated Swiss gasifier based on IISc design

20.1.3. CGPL, my second home

By 1996, CGPL had become my second home, I developed a liking for research and decided to pursue for higher degree. In the second attempt of my applying, I secured admission for MSc (Engineering) as an external registrant at Dept of Aerospace Engg, under the guidance of Prof H S Mukunda and Prof P J Paul, and Dr T S Channesh of KSCST as the official supervisor. My research problem was related to investigation of producer gas operation in spark ignition engine at high compression ratio. As the scope of the research problem widened, I upgraded from MSc to PhD. The research work provided interesting insights with respect to smooth operation of a spark ignited engine on producer gas fuel, without knock at compression ratio as high as 17. This was the one significant piece of finding from the research work and much against the perception of many experts in biomass gasifier field including Dr. Thomas Reed, Biomass foundation, Colorado and Prof PP Parikh, IIT Mumbai. The experimental work was supported by computational work involving zero-dimensional modelling with some inputs from CFD studies. The knowledge gained as a consequence of this research later helped in adaptation of commercial gas engines that were designed for biogas to operate on producer gas. We worked with engine manufacturers such as Greaves cotton and to a large extent with Cummins India Ltd.

All along with the gas engine research work, there were several developments that took place at CGPL with respect to biomass gasifier. Post $-$ Swiss tests, there were several changes in the sub-systems. The reactor design metamorphosized from water seal bottom to a screw based extraction system, mainly to accommodate high ash content fuel – biomass briquettes. There is strong reasoning behind this change: until that point of time, two different approaches were pursued for the reactor design based on the type of biomass - for the agricultural waste like rice husk and others, a cyclone reactor was pursued for a long time, under a project - POBIG, sponsored by MNRE. This approach was able to process pulverized agro-waste but did not yield a gas that was suitable for engine operation. So, this approach was abandoned, and it was decided to briquette the agro-waste and use them in moving bed downdraft reactor. So IISc gasifier reactor had become a universal design for all types of including municipal solid waste. The other major development was the replacement of sand filters with a chilled water scrubbing system. This improvement largely improved the gas quality, and the gas was amenable for use in gas engines. The shift from dual-fuel operation to gas engine also vastly improved the plant economics. This I would say was one of the biggest achievements and an important milestone in the history of IISc gasifier R & D because this laid the pathway for commercialization through technology transfer to eight companies, which included one from Japan.

20.1.4. The leap into commercialization

The commercialization took a huge leap from 2002 or so, where several systems were deployed for a range of applications which included 1 MWe grid linked system (Arashi Hitech Biopower), captive industrial power (Senapathy Whitely, Hatsun), rural/village electrification, industrial heating application – drying of crumb rubber (many units in Kerala), tea (at Conoor), marigold flower, aluminum fluoride etc. These include kWe scale to MWe rural electrification systems that were installed in Ungra/Hosahalli and Biomass Energy for Rural India (BERI) project in Tumkur district, which was funded by UNDP. For the power generation units, Cummins producer gas engines was deployed.

I was involved in commissioning several such units, which also involved training and troubleshooting activity. Many of these systems were installed in southern part of India, here it is apt to mention contribution and active participation of some of the key team members which includes H V Sridhar, Suresh and several technicians - Venu, Anil, Chennakeshaviah, Ananth and Shankar. The commercialization of gasifier involved a lot at the field level The involvement was such an extent that many times both the licensee and the end user had to be educated on issues which looked trivial, yet important – quality of biomass and its implication on performance.

Photo 20.2 The large-scale systems - HATSUN-AGRO at Cuddalore and the gas engines at Arashi HiTech biopower

20.1.5. On to Suranaree university, Thailand

I had also the opportunity to travel overseas for providing technology support to one of the licensees, Satake Corporation. One system was installed at Suranaree University in Thailand (2006), it was a 100 kg/hr gasifier coupled with Cummins gas engine and operated on rice husk briquette. The briquette had good mechanical integrity and were produced using a Japanese make briquetting machine. In fact I never saw these high-quality briquettes in India. Another installation was in the factory premises of Satake Corporation in Hiroshima, Japan (2003). The gasifier was a 30 kg/hr, coupled with a diesel engine for dual-fuel operation. I travelled to Japan with Mr. Bikas Bose, Indian representative for Satake Corporation. I found Bikas to be a lively person, to my surprise he has several acquaintances from Kolkatta working in Japan, so did not face much issue with the food as I was a vegetarian. We made it a point to visit both the memorials of World War II bombing sites - Hiroshima and Nagasaki.

20.1.6. The program, REACH

I got involved in some diverse activities such bringing awareness about energy among rural students in Karnataka. The program was named REACH (Renewable Energy Awareness Campaign for the masses) - an audio-visual aided educational program, which addressed high school students, technical students, faculty members and entrepreneurs with more concentration in the rural areas. Myself, Gayathri and a few faculty members from ASTRA (now CST) made presentations to a few hundred students in and around educational institutions in Mysore, Tumkur, Belgaum etc. Likewise, there were many national and international training programs that were held at a lab as part of SDB and ABG projects. Had the occasion to meet with academics, entrepreneurs, administrators. Invariably there used to be a visit to one of the field installations.

Photo 20.3 Participants at the international training at CGPL

Even though I was an employee of KSCST, my involvement was only through CGPL. The only direct contribution that I remember is being involved as a representative from nodal agency from Karnataka state for certification of gasifiers under central subsidy program of biomass gasifiers. I remember to have visited about half a dozen beneficiaries in this connection.

20.1.7. The Bamboo mission

Mr. Vinay Oberoi, Advisor, National Mission for Bamboo Application, DST, Govt of India brought to our notice a problem of sudden dying of bamboo in the North-Eastern states of India. So, a R & D activity was undertaken to address this issue. Bamboo is a fast-growing fibrous plant grown in abundance in India. In India, one particular species of bamboo namely 'Melocanna baccifera', estimated to represent over a sixth of the country's growing stock of bamboo, was facing the threat of gregariously flowering between 2004 - 08. The flowering of Melocanna baccifera was an event of great significance wherein large tracts of land would be affected, as bamboo forests burst into bloom and then died. This sudden death of bamboo in huge quantity was expected to significantly increase the rodent population and therefore there was an urgent need to identify ways and means by which several thousand tons of bamboo could be put to effective use in short span of time. So, there was definite need to immediately use or preserve or extend the shelf life of the bamboo. Under one of funded projects, torrefaction of bamboo was successfully attempted wherein trails were conducted in a kiln of 1 ton/day input capacity. Based on the lab studies it was found that there was an enhancement in energy density by 20% against green bamboo between torrefaction temperatures of 250 and 260°C. Apart from energy densification, torrefaction process made the material hydrophobic, which helped in long term storage. This batch-type kiln had completed successful trials at the laboratory and had potential to be located in a smelter industry where the torrefied bamboo could replace normal charcoal for metallurgical purpose.

Touching upon the important part of academics i.e. publishing and participating in international conferences, I had submitted abstracts for the International combustion symposium but got declined both the times. From the lab, we made it a practice to regularly participate and contribute for the European biomass conference. So many of us from the lab participated in annual conference held in Germany, Italy and France. Most of the times we had to live on shoe string budget, during the conference in Italy, our stay was at a home, which was built out of used ship container. It was a furnished with a wash room and the stay gave us a totally a different experience!

Photo 20.4 Left: me, right: Three of us including H. V. Sridhar and Subbukrishna at the poster session of the European conference on biomass, 2006

20.1.8. Biomass stove development

There were many other activities in parallel, the prominent one was the stove development. I was involved in initial stove development program, which essentially was a fan powered pellet stove for domestic cooking application for British Petroleum Energy India Ltd. Several variants were prototyped including a combi stove (one LPG burner + one biomass burner), the efficiency of biomass stove was about 43%, with a burn duration of over an hour with biomass pellets. Field trials were carried out in six villages of Maharashtra and Tamilnadu on behest of BPEIL, with moderate success and feedback for improvement. The stove development further advanced towards ejector-based design for larger heat requirement application. Bhaskar Dixit got involved intensely along with Prof Mukunda.

I experienced IISc truly being an institution of higher learning and of national importance, in particular CGPL because there was always a constant flow stream of inquisitive visitors other than international scientists - farmers and local entrepreneurs in their eagerness to find solution using biomass for rural application. Many devices were developed and deployed for a variety of applications apart from domestic cooking for small industries application such a cardamom drying etc. Likewise, I was involved in many training activities for national and international participants, which in some sort became a regular activity and part of sponsored project from MNRE.

CGPL was a known place for celebrations. One regular annual event was the Ayudha Puja during Dussera festival. I remember some of animosities between lab technicians used to vanish around that time and they used to conduct the event very cordially. There were many other social gatherings on occasions such as some staff or student wedding.

20.1.9. My view of CGPL

I will not be doing justice to this writeup without specific reference to CGPL. As mentioned earlier, CGPL was my second home where many a times I spent over 10 to 12 hours daily, engaged in my own research and other ongoing activities. I feel in many ways the lab had a unique culture in terms of discipline, high quality science pursued and comradeship among the working staff and students. It was true temple of learning with little margin for mediocracy or politics. We never felt dearth for funds for any development work and I attribute the success the lab witnessed entirely to the leadership – Prof H S Mukunda, the main driving force, who kept all of us on feet most of the times! The drive and passion that he exhibited was no less than CEO of a company. Prof HSM displayed rare quality of motivating his staff and students; I am surely one of the beneficiaries of his advice. In many a sense I found him to be a selfless person, totally dedicated to science and was readily accessible for any help. The other person whom I treat with the same reverence is Prof P J Paul. Even though Prof PJP and Prof HSM were of contrasting personalities, yet they jelled very well and formed a wonderful team with Dr NKSR and Dr Dasappa. Prof PJP hardly spoke, many of us used to say – “PJP will start to think when others stop”. This statement comes from the respect that he commanded as an intellectual with a deep and logical thinking capacity and coming up with out of the box solution many a times! Prof PJP though serious had a wonderful sense of humour which I personally witnessed during the field visits with him. In many ways I feel Prof HSM and Prof PJP had a strong influence on me in terms of making a better and logical thinker. This quality that I imbibed at the lab helped in great deal in later part of my career at Siemens. I am grateful to the lab for the opportunity that I got to pursue and complete my doctoral degree, I feel luckier than many of my contemporaries because I found my life partner at the lab, which is something for me to cherish for a lifetime. The other aspect that I gained was in terms of improvement of my personal health and the reassurance that I received from all the colleagues at the lab.

20.1.10. Out of CGPL - on to Siemens Corporate Research

By 2007, I began to feel that research was getting a back seat at CGPL as much of the efforts were towards commercial activity - supporting for the licensees. I therefore felt a need to explore opportunities outside IISc. Since I was not so young for a post-doc and not keen for full time teaching work in a private institution in Bangalore, I looked for opportunities in industry. This led to my quitting IISc (CGPL/KSCST) after nearly 16 years! it was not an easy decision, nevertheless it was taken.

I joined Siemens India in September 2007 to start a R & D program on renewable energy. The research unit was to become part of Siemens Corporate Research & Technologies (CT T), Bangalore. My initial responsibility was to create a technology roadmap and present to Siemens Global CT T in Germany. Once the program approval was sought, a space was identified to establish a R & D facility and to build a research team. I was fortunate to have a team of young researchers with master's degree from IIT Mumbai initially and subsequently Masters/PhD from other IITs in the country and from overseas. I was the Program manager for technologies related to biomass till I formally quit in May 2013.

The R & D facility named Siemens Renewable Energy Innovation Centre (SREIC), established as a part of "off-grid energy for emerging markets", had the mandate of developing 'low cost, high tech and environmentally friendly' renewable energy-based solution for distributed power generation application. The selected areas of clean and renewable sources of energy were biomass, solar and hybrid solutions. Initial research work started with biomass-based technology and subsequently research on solar and water were added.

The first year got largely devoted to planning of program and setting up of SREIC centre. One of the major initiatives was to improvise the existing biomass gasifier system and package them as containerised power solution for emerging markets. Since the program was not initiated to develop gasifier technology from the scratch but to license the gasifier technology from IISc, a commercially available 35 kg/hr open top-down draft gasifier system (from one of the IISc licensee) coupled with a 25 kWe producer gas was set-up at the SREIC as pilot plant for testing and further technological improvements. The approach was to use IISc gasifier reactor and develop a few technologies whereby there in value-addition from Siemens.

20.1.11. Electrostatic precipitator for gas clean-up

Since the containerized solution required a solution of compact footprint and with system elements being less water and energy intensive, a major initiative was taken up to develop Electrostatic Precipitator (ESP) as the final stage of gas cleaning prior to feeding of producer gas to gas engine.

Initial efforts were to develop a wet ESP, with minimal water requirement and subsequently move to dry design. This development effort was highly successful and still cherish it. The design for ESP largely came from Dr Thomas Hammer, a Physicist at Siemens Erlangen. I felt him to be a warm and pleasant person and comradeship that got developed working with him helped me to some extent overcome the loss of companionship which I missed after leaving IISc. Initial work started with a wet tube type ESP, the design was a wire placed concentrically within a cylindrical tube. The gas cleaning seemed adequate but continuous operation could not be sustained due to either arcing or wire snapping as the carbon or carbon and water mixture got settled on the high voltage insulation. Several minor design changes were attempted over a period of one year but without much success. The tube ESP was abandoned and a new design, namely plate type ESP was developed. One major difference that I could cite working in a corporate versus the academic research is that in academics one has the freedom or free hand to explore - build and test a new concept or idea in no time, but in corporate the rigour of procurement was so intense that the fun of learning got killed by the time the equipment was made available. But at the same time there were several positives that I experienced working in an industry such as toll gate technology development process, periodic reviews, providing highest importance to safety of personnel, standard operating procedures for every test equipment and a safety drill before the commencement and closure of day's activity. Also, documentation, preparation of test reports and presentation skills got honed with time. As a standard practice no visitors were allowed during any testing activity and any visit had to be pre-planned and approval sought. One such visit I was able to plan was for Prof HS Mukunda, who graciously accepted and blessed the facility. The only other associates/licensee of IISc who visited were Mr. Amar Kumar and Mr. Aravindakshan of BETEL, Bangalore.

Since the entire approach was based on the premise of using the existing gasifier design of IISc as a base technology and Siemens to provide improvisation so as to realise a containerized solution, I undertook the task of leading the Siemens leadership to CGPL, proposing for technology transfer to Siemens. Discussions did not break ice despite multiple interactions, eventually this led to weaking of my position in the company due my failure in clinching the technology transfer. As a consequence, a road map was conceived to develop own gasifier reactor technology but there was not much headway as efforts were focussed on development of other sub elements.

Continuing efforts on wet ESP, a two-stage plate type ESP was built and subjected to rigorous testing to establish its performance. The ESP was designed to operate at about 18-20 kV consuming 80 W electricity. There were some initial hiccups, eventually it turned out to be robust design and lived up to design expectations. The operation was the ESP was found to be smooth and continuous operations were successfully attained. As a reliability test, the system was tested uninterrupted for 100 h each for 50, 75 and 100% gas throughput. particulate matter and tar (P & T) levels in the gas were sampled (both upstream and downstream of ESP) at random time intervals. The analysis was carried by the same Cosmic laboratory, with whom I had established relationship during the Swiss test at IISc in 1994. The outcome of testing was positive to the extent that the gas quality in terms of permissible level of P & T was much superior to the prescribed norms for naturally aspirated engines (Norm: 50 ppm P & T). For turbo charged engines (Norm: 25 ppm P & T), the particulate matter was well within the prescribed level but tar level was marginally higher. In fact, the particulate level was as low as 10 ppm and tar about 28 ppm at 100% load operation. Overall, it was demonstrated that with a well-designed plate type wet ESP the cleaning requirements for supply of producer gas generated in a downdraft gasifier to a turbo charged gas engine can be met. The impact of this improved gas cleaning device was that the internal power or parasitic load reduced by 70% when benchmarked against IISc chilled water cleaning device, thus contributing to higher overall plant efficiency.

20.1.12. Stirling engine development

My fascination for Stirling engine technology drove in formulating a technology development program involving integration of biomass-based combustor with the Stirling engine. A 38 kWe Stirling engine was imported from USA. For understanding of the system and holding technical discussion, I made a visit to the company in Michigan, USA in 2008. This being my maiden and only trip to US, I made sure of visiting the innovative Ford Museum in Dearborn, Michigan. The discussion with the Stirling engine company owner was pleasant and useful. The engine is an external combustion engine which uses hydrogen as the working fluid (5 MPa), operating on fuel such as propane or LPG. It took some effort to import and install the engine at Bangalore. As a contingency measure one young engineer from the R & D team was trained at the manufacturer facility in USA. The biggest challenge was safe housing of the fuel gas - LPG fuel bank comprising of 24 cylinders containing 19 kg LPG. The supply line was provided with slam shut-off valve, flashback arrestor, safety relief valve for safe operation and protection of the gas bank. Similarly, the hydrogen cylinder was housed in a safety cabinet. The engine could be started using grid power and later operated in off-grid mode. The necessary power electronics for operation in off-grid mode was developed by in-house power electronics team members. Initials trials were carried out to understand and evaluate the engine performance with LPG. Since the ultimate idea was to use Stirling engine fuelled with hot producer gas generated from a biomass gasifier, a combustor was specially built and successfully tested. A new combustor had to be built because the original burner was designed to operate on clean gaseous fuels and not suitable for burning unclean producer gas as its passages, which were too narrow, would get clogged. This being true with other commercially available gas burners, a burner was designed that could burn producer gas laden with tar and particulate matter. The ultimate goal was to use the hot products of combustion to operate the procured Stirling engine. The overall footprint comprising of gasifier reactor + Stirling engine fitted well for a containerized power solution!

A cyclone combustor was designed from first principles and CFD simulations were carried out for verification of the preliminary design. The combustor had tangential fuel and air inlets that caused a swirling flow inside it in order to facilitate fuel-air mixing and flame stabilization. The mixing and combustion performances of the combustor were characterized experimentally and via numerical simulations. Both measurements and simulations indicated good fuel-air mixing, the presence of a stable flame over a range of operating conditions and complete combustion of fuel. Measurement of particulate matter concentration at the combustor exit indicated that the combustor conforms to Indian regulatory norms (CPCB norm specifies particulate matter less than 350 mg/Nm3). The peak measured flame temperature across all experiments was 1378°C and was recorded during the experiment at $\lambda = 1.04$.

In parallel there a few other technology developments that took place, even though it was a minor work, it is worth mentioning. These were supposed to be part of “Field Ready Package” solution. Field Ready Package comprises of three components: black start - using lead acid batteries for start-up of biomass gasifier system; auto start cum controller and remote data acquisition. Meant to facilitate the biomass gasifier plant operation at remote location by the way of providing start-up power, requisite automation and remote monitoring of the operations. The other sub-system that was developed was a electronic controller for the gas engine. The original gasifier + gas engine setup comprised of pressure regulator to deliver gas at uniform pressure to the engine irrespective of the load variation.

Many times, the mechanical pressure regulator was found to pose issue of hard start and also sluggish response to load variation. So as a solution, electronic controller in lieu of mechanical system was successfully designed and tested. The performance was benchmarked against standard norms in terms of frequency and emissions and found to be satisfactory.

20.1.13. Sundown at Siemens

The R & D activities at Siemens Renewable Energy Innovation Centre got expanded into other areas. The lab space was expanded to include programs on solar power, biogas and water. Well qualified research team were involved in these activities, even though the research was incremental. The work involved making several trips to Siemens' research facilities in Germany, also participated in European biomass conferences held in Italy, France, Germany. By beginning of 2013, Siemens corporate R & D had invested for over 5 years but could not find traction from Siemens energy/power business, which was focussed on large scale conventional power plants. It was not obvious to me if they could not find customers or did not have intention to foray into decentralised power markets. So, one fine day Siemens leadership from Germany took decision to shut down the R & D centre and this culminated on 31st May 2013.

After quitting Siemens, I spent a few months at MS Ramaiah School for Advanced Studies as a Research faculty, discontinued primarily on health grounds but I could hardly see any research activity in this institution except for some computational work.

Summarizing my foray in bioenergy research for over 22 years, I thoroughly enjoyed my professional career as a Researcher and to some extent contributed to the scientific knowledge. My first innings at IISc is a cherished one, I have some pleasant memories working with the erstwhile CGPL team. My second innings at Siemens though started off on a promising note, could not sustain for longer time for reasons beyond my control. Though the research carried out was quite challenging, and quite a good amount of research work was accomplished in a short time, the sad part remains that Siemens could not benefit from it.

20.2. H. V. Sridhar

One of the benefits I got during my 15+ years of working at CGPL other than working with best brains of the world is that I could see many places spanning from Jammu to Kanyakumari and Mumbai to Arunachal Pradesh. Of course, I had good chance to visit other countries like Chile and Brazil related to work and visit France as well as Italy for participation in world biomass conferences.

20.2.1. Desi Power system

As far as my remembrance goes, my first long distance travel by plane was to Delhi, from there to Jhansi for visiting the Orchha gasifier set-up by Desi power, this was in 1997. It was both an excitement and confusion for me as I had no prior experience in boarding procedures, the virtual walkthrough given by Gayathri helped me in managing to board the plane and reach the destination. My limited knowledge on Hindi language usage created butterflies in stomach during the travel. I spend 3 days at Jhansi and during the return journey, HSM had asked me to visit MNRE and meet Mr. S.K Singh and Mr. K.K. Singh. As a person shy in nature, I felt loss of words to communicate with the officials. However, I managed to complete the task given by HSM successfully. Upon reaching Bangalore airport at HAL, I heaved a sigh of relief.

20.2.2. System at Port Blair, A & N islands

The next long-distance travel was to Andaman and Nicobar islands for training the electricity department in using the new gasifier at Port Blair in 1998. Gayathri accompanied the onward travel as she was on an independent assignment of biomass survey at A & N islands. We reached Port Blair and found that the installation of gasifier needs few more days. Hence I was allowed to join the biomass survey team to Nicobar island where we were taken to little Andaman and we could see the aboriginal Onge people. Upon return the gasifier commissioning and training work got completed as scheduled. In the meantime Gayathri could get return journey ticket and flew back, but for me the return journey ticket was unavailable, life seemed to be unbearable in Port Blair. The flight to Chennai (then Madras) was twice in a week and I was looking forward to each schedule to see if I could get a ticket. Finally, the Chief Engineer of Electrical department was successful in getting me a flight ticket to Kolkata. I reached Kolkata, there was an airport quota for train to Chennai which I grabbed and managed to reach Bangalore. Again reaching Bangalore made me celebrate by taking a day off from the work.

20.2.3. System at island in Chile

The next big excitement was travel to Chile under UNDP project for setting up the village electrification project at

Butachauques island in 1999. A team of 3 members led by G. Sridhar with Venu (technician) and myself started the travel from Bangalore and reached Chennai as 'Air Malaysia' operated from that airport. We had an 18 hour stop-over at Malaysia, hence the airlines provided us a transit accommodation. We used the time to have a half day conducted tour covering the twin towers, palace and the zoo. The next flight was from Malaysia to Argentina and the plane had a refuelling at 'Cape Town' in South Africa. We were asked to step out of the plane during refuelling, I was excited that I had stepped on the land of South Africa, even though it was for 20 minutes only. We landed on Argentina after nearly 18 hours of travel, from here we boarded a different plane to Santiago, Chile. Here, I had a first experience of passengers clapping for the crew after safe landing. We had an orientation in UNDP office at Santiago and later over the weekend we were taken to the village where the gasifier was shipped. The village was Vitacura which is located in south-west part of Chile. Here we stayed nearly for 3 weeks to set-up the gasifier and train the operators. We had difficulty in conversation as the localites were familiar with Portuguese language only, we were provided with a translator who supported us in official communication. The non-official communication in the guest house was only through sign languages, however it worked. We were paying guests in the village chieftains house and we cooked our own food as two of us were strict vegetarians. We had shipped some utensils, rice and dhal and had carried with us some spices and materials required for our daily food. One evening we cooked carrot halwa which was not to great standards of South India, but was liked by our hosts. The island village was small and we did not have any important places to visit, hence we were confined to work and living in paying guest accommodation. The return journey was same route as that of forward journey, but we did not have sufficient time to venture out in any airports. After about 4 weeks, my most memorable first international travel got concluded.

20.2.4. System at CBRI, Roorkee

It was peak summer in May 1998, me and Anil (technician) visited Central Building Research Institute (CBRI) Roorkee for testing the gasifier for brick baking. We also carried an AC drive to control the blower speed and this was to be integrated. The gasifier set-up work needed one week and we used to work early in the morning and late in the evening as the afternoon temperatures reached 46 to 48°C. During the week we also managed to spend few hours on the banks of river Ganga which flows through the Roorkee city, it was very pleasant and relaxing. In the weekend we visited Haridwar and Rishikesh, I was very excited to see these places, we witnessed Gangarthi in the evening and took a bus back to Roorkee. The mess food became monotonous but we did not have any choice as CBRI was slightly at a distance from the main city and we did not have any restaurants around. The gasifier trial was supposed to be for 36 hours continuous and with varying kiln temperatures. We began our trail at 8 am in the morning and towards the afternoon the outside temperature was high and added to it the kiln radiations made it hotter. The support staff were reluctant to work and even load the biomass into gasifier, it took lots of coaxing and cajoling from CBRI team to make them work. The night was also hot with radiations in the work area. We were awake for the entire night, after about 30 hours the AC drive stopped working, we had to call of the trials. The sleepless 30 hours work in hot conditions and aversion to food created high fever in me. We decided to come back but managed to get a Reservation against Cancellation ticket from Delhi to Bangalore in train. We took the chance as I was desperate to get back, this is when I got the first experience that a true prayer from heart will be answered by God. I was praying that we get individual berths in train and soon reach Bangalore. When the chart was displayed, we could get only one side berth, which we decided that will be shared by both of us. After the train started a family in the compartment offered two seats in exchange to our seat as one of the lady members had got a seat in a different bogie. We readily accepted and moved into, 2 days of sleep in the train and a different food did good to me and fever subsided as I reached Bangalore. I happily reached home.

Next in Oct 1998 and in early 1999, two more visits were made to Roorkee for completing the projects, the experiences remained the same, but the body had got used to Roorkee conditions, no fever was seen.

20.2.5. Systems in Sao Paulo and Belem, Brazil

It was in 2003, I got my next chance for an international visit to Brazil. This was for evaluating the performance of the gasifier at two universities, one in Sao Paulo and other in Belem which is in North of Brazil. I had to visit Mumbai to get my Brazil visa and further proceed to Delhi to catch the Air-France flight. I flew to Delhi and proceeded for international check-in, in the check-in I got a surprise that I needed transit visa for France to use the airport for changing planes. This I was not aware, the ground staff stated that they can postpone the trip by one day within their powers, if I could manage to get the transit Visa. I tried next morning by visiting to French embassy at Delhi. They did not encourage me, I had to cut short my visit and come back to Bangalore. For the first time, I returned to Bangalore with a heavy heart. Within few months the itinerary was reworked and it was ensured that I had transit visa. I could visit Brazil, to begin with Sao Paulo and spend a week there, however as I was alone I did not venture out much to see any places. The next week I visited Belem which is a small town in North Brazil. There were no important places to visit, but got a good glimpse of life and culture by interacting with people in both the places.

Photo 20.5 Prof. Mrs. Brigida and the working team with me at the gasifier location in Belem in 2003

20.2.6. Conference in Rome, Italy

We also had the chance to participate in International Biomass Conferences, the first was in Rome, Italy. It was Dasappa, me and G Sridhar who could visit in 2005. We had made an online booking of an affordable accommodation. Upon reaching there, we found that it was a container converted to a room containing 3 beds and a bathroom. It was sufficient for us. One of the days we visited the Vatican city and also the famous Colosseum. We survived on Italian vegetarian Pizzas which I could never eat using knife and fork, I had to resort to eating by my hands. We also took a conducted tour of Florence before we returned. The temperatures were low and our shirts and sweaters were not sufficient to protect us, but it being a short duration trip and our enthusiasm to see around made us brave the odds.

20.2.7. Conference in Paris, France

The next year i.e. in 2006, the international conference was in Paris, France. This time our delegation was 4 members with me, G Sridhar, Subbu and Dixit. We had booked a bed and breakfast hotel which had a good metro connectivity with the conference location. This made our daily commute easy, also the front office executive in the evening was a person having Indian roots and his parents were from Pondicherry. We took his guidance in reaching good places of visit in and around the city. We visited Eiffel tower and had a magnificent look of the Paris city from the top of the tower. After around 4 days I had a severe low back pain and this limited me to visit conference and come back to hotel and not explore the city further. The conference ended and we took to our return journey.

There were lots of repeated travels to support the gasifiers installed in various locations, the prominent ones are Ramanagara, Coimbatore, Harihara, Cuddalore and Kancheepuram. I also visited Jammu for supporting Hindustan Pencils. I also had a good chance to visit North

Eastern States of Assam and Arunachal Pradesh along with Prof. P.J. Paul. We were supporting Cummins to educate their field staff on gasifiers. In Guwahati, we visited the famous Kamakhya temple. The visits came to a halt in July 2007 when I decided to shift to a corporate job. Looking back all the visits were fun filled as well as filled with tension as we had to diagnose and solve field issues and win back the customer trust on using gasifier. I personally gained in enhancing my self-confidence due to several visits and the interactions it provided. So at the end it was a journey well taken. I thank all my ex-colleagues in CGPL for the bonding, support and learning I got during my stay at CGPL.

20.3. P. A. Ramakrishna, Dept. Aerospace Engg, IITM

20.3.1. At IISc

I joined IISc in the year 1994 (which some of friends later on would tease about very fondly as "You know when this guy joined IISc, he joined that year when there was a plague in Surat". The idea being, if we were to ask our grandparents their age they would hardly remember it and would say that they were born after this plague or after that calamity). My initial few days were very pleasant beginning for rather very eventful life later on. We were asked to meet the HOD the first day and Prof. A V Krishnamurthy told us about what to expect in IISc in simple terms and these words still ring in my head to this day. He said "Welcome to IISc Aerospace Department. You have been very good in your studies earlier and therefore you are here in a premier institution like IISc only because you are very good. You have shown a very good ability to take on things which are challenging and hence you are here. Now as you are here I say if you have two assignments to submit on the same day, please don't come and complain to me. You could have an assignment and an end semester on the same day please do not complain to me. You could have two end semester exams on the same day please don't come and bother me about it." So essentially he laid out the rules of engagement right on the first day.

So, after that day the classes began and life started going easy in the beginning week and became rough afterwards. The first week, we were trying to look at what courses to take and all that and I do remember trying to take this extra course on 'Liquid Rocket Engines' offered by Prof. P J Paul (PJP as he was called in the lab). When I went and enquired in the office, they said he had gone out the country for a short visit to attend a conference. I had thought he must have been quite a reputed person in his field. We also realised Prof. H S Mukunda (HSM as he was called in the lab) was to teach us 'Mechanics and thermodynamics of propulsion' was also not in the country and would only return after few days. Later, I realised that both of them had gone to attend the combustion symposium. I did not get to take that course on Liquid Rocket Engines with PJP and that has been a regret for me to this day. HSM classes started a little late in the semester and I really got interested in propulsion as a subject. I had a liking towards thermodynamics, heat transfer, combustion and fluid mechanics and in addition his style of teaching really appealed to me. It was really amazing to me that his ability to remember numbers and also do very quick arithmetic without a calculator. I later realized that he was just being true to his name High speed Mathematics/Mukunda (HSM). It also trained me later on to do the same, but probably at a lower level. His classes used to be very lively and would make you participate in the class. The other aspect of his teaching was that he would take all classes at 8 o'clock in the morning. Some days we would wait for him to come on his blue Lambretta and open the doors for the building. He was a very friendly person and I developed a liking towards his teaching and to propulsion in general. However, there was one hurdle, he was known among the student community at that time as a tough task master. So at the end of the first semester, when we had to choose projects to be pursued later on much against the advice of my then roommate Dr Vikas Gupta, I did go and speak to HSM asking for his permission to pursue my ME project with him. He had asked me if I would be interested in working on the pulse detonation engine.

In the second semester, my experience with CGPL started with the combustion course. It was then offered jointly by PJP and HSM with the first part was being taken by PJP. Strangely, he also had a Lambretta, a light blue variant. After the first two classes my real feeling about process PJP was that he must be some side kick of HSM who was no good. It was sometime later that I realized how horribly wrong I was and that he was such a good teacher who had very deep understanding of the subject. I need to qualify here, what I mean by good. He would if you were to ask him a doubt he would go to any level to make you understand and that having spent close to two decades teaching myself is a very rare and an enviable trait to possess. We also realised, when we were taking the course was that we should not let PJP keep going at his pace, but we need to ask him doubts wherever we did not understand and also prevent him from finishing two or three chapters in one class.

The other impressive thing about CGPL was it had its own conference hall in which we would have combustion classes. After the first half, HSM started taking all his classes in his office. It was very difficult class to attend because there was no distance between him and us and it was extremely difficult to even take eyes out of his eyes. I do remember Dr. Nikhil Patel (Nikhil), Dr Saurabh Apte (Apte) and self where the ones who are taking this course and in between Nikhil took off for his marriage. This meant, we were only two of us so he would write something on the board come back and sit down and look at our faces and say “tell me what you understand”. One of his famous utterances was that we should know about adiabatic flame temperature even if we were woken up in the middle of the night. Towards the end of the second semester, I remember being asked to pursue a project on vortex combustor, which was later changed to Sandwich propellant combustion. The first thought that came to my head was what is this sandwich all about and then I realised that this was a problem that was going to keep me busy for very long time in my life; as recent as last year when Dr. Chaitanya graduated. Towards the end of my 2nd semester HSM asked me if I was interested in continuing for a PhD and I was super elated that a person like HSM was asking me If I would be interested in continuing my work with him and PJP. I immediately said yes to it.

I started my work on sandwich propellant in the lab. The other aspects of the lab used to appear very dull from an aerospace perspective for me except one room at the entrance of the lab, which had this Rolls Royce dart engine cut section and a liquid rocket engine which was very impressive for a propulsion engineer. But the rest of lab was all gasifier, burner, diesel engine and other things, which to my aerospace mind was not glamorous back then. We were only very few research scholars at that time I do remember Nikhil Patel was research scholar and I was an MTech project student. The lab used to boast of one of the latest computers and soft wares that one could dream off at that time. I remember Nikhil and I would have long conversations about how things should be in the lab and how things are not it sometimes used to result in some unpleasant conversations.

The one interesting aspect about me is that I think I was the only student in CGPL who has been taught by 3 of CGPL's main people. Apart from HSM and PJP, I also took a course on estimation of aircraft costs by Dr. N K S Rajan. It was a course where I had to learn visual Basic and execute the project.

My main project on sandwich combustion was an interesting one where in one had to model both gas and solid phase heat transfer with the appropriate interface coupling conditions. For a long time the computations were throwing up very funny results and I was asked to give my code to PJP who said that there are 2 lines in the condensed which was making the code behave funnily and hence commented it. I was very happy that finally I was getting my results and even unsuccessfully communicated a paper to the Combustion Symposium. Little did I realize that my happiness was short lived as I had to struggle for long years after removing those two comment statements as they were only stop gap arrangements and it took me a long time almost 4.5 years of my PhD life to overcome the same, which I will come to a little later.

During the M. Tech project, the interface of gas and solid was assumed to be fixed and that the solid propellant was coming up to this surface at a rate equal to the burn rate. This was not a very accurate description of the problem and had to be relaxed with a feature which is described as a surface following grid. This is a very challenging problem as very few groups (3 – 4) have been able to solve this problem to this day. As the surface regression depends on the energy balance on the surface and the surface regression in turn determines the energy balance. As I got down to solve this problem, I did not understand how deep the problem was and how much of my time it would take.

My PhD life was little dull for some time trying to overcome this, till one fine day HSM asked me to design a Hybrid rocket. Dr. Amit Kumar who joined the M. Tech program in 1995 and he stayed back after his M. Tech project at CGPL as project assistant. It was during this time that HSM told us that we need to show something for the 'Open Day of IISc' and why not show Hybrid rocket demonstration for this. We asked him the time to do this, he said one week. I do not remember sleeping for more than 10 hours on all days put together in that entire week. We had to make calculations and design something that could lift itself up on rails as shown in the photograph 20.6. It was here that I heard a rare word of appreciation from PJP when we showed the final model. I also learnt how to apply a mild pressure on people when they are working very hard. One morning when we showed HSM the final model he appreciated it and said maybe we should invite the director for the show. This got us going further to make all systems work more reliably. Finally, we designed a hybrid rocket as shown in Fig. 20.7 with polypropylene as fuel and gaseous oxygen as oxidizer. The simple control that we had which would make it go up the rails and come down was the pressure regulator for the oxygen supply. This system, I am told still continues to enthral crowd during 'Open day'. It also was loaned to the famous "'Visvesvaraya Industrial & Technological Museum'" for several years. It was also during this time that I realized that a lot of people will come forward to help you if they perceive you as being invested in something special. I have to acknowledge the help received from Dr. Anil Kumar (Anil), Lathe Anil, Dr. Sriram, Nikhil and many others some of whom also burnt the mid-night oil along with Amit and self.

Photo 20.6 The Picture of Hybrid rocket moving up on hidden rails with gaseous oxygen as oxidizer

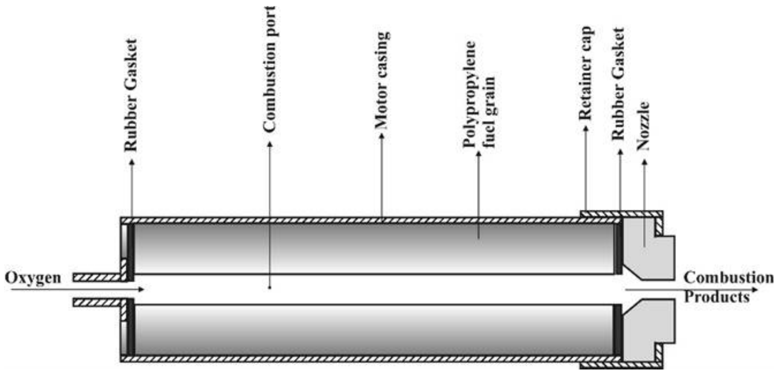


Figure 20.7 The simple design of the actual hybrid rocket motor with polypropylene fuel and gaseous oxidizer

During the days and nights of struggle to address the surface following grids which were required to solve the problem, I had a few heated debates with HSM. But, I should add that most times although he would forcefully put forth this views, he would say “You are the research scholar and you should have the final say in what needs to be done”.

Finally, after a lot of struggles we were able solve the problem of the surface following grids. One particular issue that needed to be resolved in which PJP played a major part needs to acknowledged here. I was repeatedly getting results which showed the propellant to quench and it was then that he suggested to check for the Denison and Baum stability parameters for AP combustion. To our (HSM, PJP and self) utter disbelief we found that most of the values used in literature which we were going with lead to unstable combustion.

Once this issue was sorted out, we were able to get results for the sandwich propellant combustion and also present the same in the 2002 Proceedings of the Combustion symposium at Sapporo, Japan. It was also a little disappointing that we were not the first to crack this problem but a group from UIUC beat us to that. It reminds me of HSM's accusation on me that I sometimes strive for perfection needlessly and this can delay things significantly. I have learnt from this very costly mistake.

The results obtained by us and presented in the Symposium won us a lot of accolades in the propellant combustion community.

There was an interesting incident about HSM that needs to be documented. I had tried to get funding to go for the conference but was somehow unsuccessful. At this point, HSM made sure I attend the conference by taking out money from his personal contingency fund, which is quite rare for faculty to do. I am deeply indebted to him for the same as it gave me an opportunity to make a comparative assessment of my work with the best in world. Without this opportunity, I would probably have felt for a long time that the work might not be on par with the world. This incident also taught me how to deal with my students the right way meaning you can push hard to extract the best out of them, but you also need to remember that you need to support them too.

Towards the fag end of my thesis there was an interesting incident that took place. Prof. Roddam Narasimha wanted to recreate Tippu's rockets and therefore approached HSM for help with the propellant part. The task fell on me and Sudarshan and we worked night and day only to record absolute failures as propellant became an explosive. In the process we managed to spoil some 3 vices and a finally gave up our effort when one of the strong room's door was blown away. This was primarily due to the fact that instead of using regular charcoal we ended up using activated charcoal. As they say man learns more from mistakes than from successes, it later on opened up a new area of research in composite solid propellant.

20.3.2. Beyond IISc...at IITM

A few months after attending the Symposium and Sapporo, Japan, I submitted my thesis and in due course of time moved out of CGPL and IISc in September 2003. It took me a total of 9 years to complete my ME and PhD. This was the reason that my friends used to tease me as "......he joined that year when there was a plague in Surat". My sisters had a different take on the time I spent in CGPL, they said what kind of womb is this, which keeps people for 9 years.

Further, there were a couple of areas of research that I managed to pick up from my stint at CGPL apart from propellant combustion modelling. These are namely hybrid rocket research and something on activated charcoal as an additive to composite solid propellant. On the hybrid rocket front quite-a-bit has been done. At CGPL a small system with polypropylene as fuel was developed while the work at IIT Madras was entire focused on paraffin wax as fuel. A brief summary of the hybrid work at IIT Madras is best summarized in the next few lines.

I have through my research scholars (Dr. Rajiv Kumar, Dr. Gaurav Marothiya, Dr. Nikunj Rathi) extensively worked on hybrid rockets. We have developed hybrid rockets with a burn rate of 7 mm/s with gaseous oxygen and wax and aluminum based fuel at a Gox of around 30 gm/cm^{2}s. The fuel block also had very good mechanical properties that it could be used as a cartridge loaded grain. The percentage elongation with around 50% Aluminum added into the fuel was around 5 – 6%. Novel techniques have been developed to ensure more than 95% combustion efficiency in a combustion chamber with no pre or post combustion chamber. Based on the above, with wax and gaseous oxygen a system was developed for ISRO, which had a thrust of 1 kN and operated at an Isp of 300 s at sea level at a pressure of around 60 bar for around 4 s.

On a similar line a small thruster was developed for ISRO based on liquid hydrogen Peroxide with 92% concentration of hydrogen peroxide was developed for ISRO. Here, technology was demonstrated for using hydrogen peroxide without having a catalytic bed to decompose the hydrogen peroxide and directly injecting hydrogen into the combustion chamber and with wax and aluminium as fuel.

The work on activated charcoal that was later followed up Dr. Sumit Verma and Dr. Ishitha Kumar showed that addition of activated charcoal in composite solid propellant leads to increase in burn rates while significantly reducing the burn rate pressure index and reducing agglomeration.

20.3.3. ……And so

As they say, man is only a collection of memories as he grows old, I have very pleasant memories of the lab and IISc in general. It gave me a chance to rub shoulders with some of the best of our previous generation and also some of the best minds of our generation. I cherish my association with Nikhil, Anil (both), Sudarshan Kumar, Dixit, S2, S3, S6, Biju, Jaymurthy, Dr. Debasis Chakraborty, Lazar, Basani and Subbu. It has been really an enriching experience and one that I shall cherish till the end. It also taught me a lot about my profession “Propulsion” and a lot more about life in general. Even to this day I draw a lot of courage and inspiration from my days in CGPL and IISc.

20.4. Varun Shivakumar, Dept. Mech Engg., IITM

20.4.1. Initial years, 2007 - 2009

I joined the Department of Aerospace Engineering in August, 2007 for MSc (engg) in the propulsion stream immediately after my B.Tech in Mechanical Engineering from NIT Trichy. I was aware of the lab (CGPL, that is), its core group and that Prof. H S Mukunda is a prominent member of the group from the internet searches I did before joining the institute. One other thing that caught my attention was the course titled “Mathematical methods in combustion” by HSM – I was intrigued by the title. But I did not realize that Prof. HSM had retired a few years ago; that became clear after the meeting with Prof. B N Raghunandan (the Chairman of the department at that time). I met with a few faculty members (Sivakumar, Lakshmisha, P J Paul, T S Seshadri and NKSR) and discussed potential research topics. These meetings went on for a week or so and then I made the decision to request NKSR to be my advisor and he accepted. I was immediately allotted an office space in CGPL and I started attending course lectures. For my research, I was expected to start running some reacting flow CFD calculations for a Gas Dynamic Laser application. In the first semester I spent only about 20% of my time in the lab, mostly working on picking up some CFD skills - the rest was spent attending lectures and at the coffee board. A few times in the initial months, I noticed HSM visiting the lab - once or twice a week he would arrive at around 10 am, park his grey kinetic nova in the space opposite the lab and would be seen immediately going for a walk with a faculty member or one of the other lab members. Sometimes I have seen him showing a visitor around the lab.

A few months later, Arvind and Abhishek (at that time PhD students in the lab working with Prof. PJP) told me about the "Understanding Combustion through images and videos" project and wanted me to be part of the group involved in setting up combustion experiments for video graphing. I was introduced to HSM by A & A and the suggestion was made that I should be part of the group - he immediately agreed. In addition to helping A & A with the flame tube and droplet combustion setups, I was assigned the task of setting up the wood sphere combustion experiment by HSM. The biomass packed bed experiments and the propellant strand regression videos are my other contributions to the project. I was paid Rs. 4000 from the project every month for about a year for this work. At that time this was 50% of my scholarship and was almost exclusively spent on dinners! My involvement in this project was the starting point of my interaction with HSM. But at that point I do not think HSM considered me as a potential PhD candidate. That happened a few months later and I am pretty sure it was triggered by what I have described in the next para.

HSM had given the problem of CFD simulation of gas phase reacting flow in Oorja stove to a M.Tech project student (from one of the local engineering colleges). One day I couldn't help but overhear the conversation between them on the choice of models etc,. I felt that the approach taken by the student would not lead to useful results and a different one was needed. Without any inhibition, I went ahead, interrupted their conversation and shared my ideas. HSM asked me to take over the calculations from that point onwards and must have seriously started considering me as a potential PhD candidate. I am quite sure of this because his questions to me after this incident became pointed about what I was doing and why I was doing what I was doing! I did not have good answers for these questions except that I told him that I was planning to go abroad for a PhD and believed that a MSc (engg) degree from the institute would help me get good PhD positions abroad. Having found out that I am planning to do a PhD, he offered me the problem of studies on Oorja stove as a thesis topic. On one side I was flattered and on the other the idea of working on stoves instead of a fancy propulsion problem bothered me (my lab colleagues were studying supersonic mixing layers and detonation!). Around this time a serendipitous thing happened - due to a delay in the arrival of the police verification report from my previous address, my passport application was stuck at the Bangalore office.

Because of this I could not take my GRE on time. Also, I spoke to a couple of my friends in the department (Abhishek was one of them) and I was told that I should not even think about it and just accept HSM's offer. I did a week or so later. HSM spoke to NKSR the same day and told me that it's done in his characteristic style! My views on my decision to work with HSM, mostly developed retrospectively, are summarized later.

20.4.2. Mid years, 2010 – 2012

Things moved very quickly after this. I more or less completely abandoned my earlier work on GDL and started focusing on simulating the gas phase combustion process in the Oorja stove. In Parallel, experiments were planned, with help from Srinath (now at the Fire lab, Jain University), for detailed characterization of the stove performance. The issue of smoke and spike in CO during the transition from gasification to char mode was resolved by adjusting the ratio of primary to secondary air (this problem was brought to HSM's attention by First Energy and further details were gathered during a field visit in which I participated). The results were communicated to First Energy and a model domestic stove with close to LPG like performance (both in terms of efficiency and CO emissions) was built and tested. While that modified domestic model was not commercialized, the ideas were used to scale up the stove to 15 and 30 kWth; these designs did well in the commercial kitchen segment. All these aspects formed Chapter 3 of my thesis. Chapters 4 dealt with density effects in packed bed flame propagation and Chapter 5 was on 'Universal flame propagation in packed beds' (a piece of work that gave me some confidence that I am capable of theoretical thinking). Though the problem of accurate global kinetics for CO oxidation for predicting stove emissions was not satisfactorily resolved (my PhD student Syed's thesis deals with this issue in some detail), it was felt that I had enough to submit the thesis, which I did in February, 2012.

20.4.3. And further, 2012 - 2013

With the passing away of Prof. P J Paul in Feb, 2012, things were a bit gloomy at CGPL. In the weeks following Feb, 2012, Prof. HSM was away in IIT Ropar teaching a course on propulsion. By then it was very clear to me that HSM wanted me to take up the task of resolving the instability problem in tactical SRMs - a sort of a second PhD. He started taking me along to DRDL for the meetings on this topic. I did some calculations to estimate damping coefficients and the results were presented in one of the meetings. It was my first exposure to affairs at the highest level in a DRDO lab and it took some time for me to position myself. The work which brought out the connection between post-DC shift dynamics and cyclic extinction-ignition of solid propellants was something that I believe made a deep impression at the highest levels of DRDL. What ensued was intense research on the problem of instability in solid rockets which reached a mature stage in late 2018 (with the completion of the development of the Heterogeneous Quasi 1-D model - HeQu1D for short).

My attempts to find a suitable post-doc position during 2012-2013 were not successful. HSM suggested that I should start looking for faculty positions in India. I reluctantly agreed (the reluctance was mostly due to lack of confidence and also because I had only 2 journal publications with 1 in the pipeline) and wrote to IIT Hyderabad first to test the waters. This was in September, 2012 just after I had successfully defended my thesis. My talk at IITH went very well - there was a power cut in the middle of my seminar; instead of waiting for the power to be restored, I continued with chalk and blackboard. That, I believe, must have led the Chairman of the Mechanical Engineering at IITH to immediately ask me to apply for a visiting faculty position. I never applied – somehow, I did not develop a liking for that place. But I gained a lot of confidence in my abilities as a potential academic as a result of this experience. HSM had suggested that I apply to IIT Ropar; I did that and also applied to Mechanical Engineering, IIT Madras (which I did following Prof. P A Ramakrishna's suggestion. I wanted to apply only to Aerospace at IITM; but aero was not hiring in propulsion at that time).

20.4.4. Journey after CGPL

I joined IIT Ropar (in Punjab) as an Assistant Professor (on contract) in May, 2013. I had also applied and was interviewed in June 2013 for the position of Assistant Professor at IIT Madras (in the Department of Mechanical Engineering). I was offered the position in July, 2013. I moved from Ropar to Madras in December, 2013 after completing a semester of teaching (I taught Propulsion Technologies as an elective for the senior undergraduate students at Ropar).

Recently (in March, 2021) I was promoted to Associate Professorship. In these years, transforming the HeQu1D framework to a design tool of use to practitioners has occupied a major chunk of my research time. The HeQu1D MATLAB code is now accepted as validated against a wide range of data by practicing engineers at VSSC and HEMRL. Work is underway to make it a standard tool for propellant design in these laboratories. It goes without saying that all this is due to the constant encouragement of HSM (harassment is his preferred term for this!). To the best of my knowledge, HeQu1D model in its current form is the only modern combustion theory - it provides an accurate answer to a practical question with a few seconds of calculation in a form that is directly usable by practitioners. That I feel confident to make such a strong statement is a result of several things - both technical and non-technical. I will only describe the most important non-technical aspect here - that is the marked transformation in my sense of ownership of the theory, from that of someone playing second fiddle to being the primary custodian of the ideas, over the last 6-7 years. This transformation is again a result of HSM's encouragement - before drafting the crucial 2016 Combustion and Flame paper describing the core of the HeQu1D model, I took HSM's suggestion and gave a presentation of the main ideas to Prof. Forman Williams from UCSD (this was in December, 2015 when Prof. Williams was visiting IITM to deliver lectures as a part of the Combustion Institute Summer School). The feedback I received from him was overwhelmingly positive and this was crucial in strengthening my confidence in the capabilities of the model. From this point forward, I became a lot more aggressive in pushing the model further - the paper on extension to aluminized propellants came out in 2018 (Combustion & Flame journal again); the perturbation model for response function came out in 2020 (CTM); 2 MS theses were written on this subject at IITM. HSM continues to take active interest in this problem and my interactions with him are continuing with the same intensity. The effect of aggressive sense of ownership of ideas has also spilled over into my research activities on biomass and coal gasification. On this front also there have been industry interactions of significance and some of the ideas have reached the product development stage.

S. Varun kumar, M. Zaved and H. S. Mukunda, A novel approach to composite propellant combustion modeling with a new heterogeneous quasi one-dimensional (HeQu1-D) framework, Combustion and Flame, 173, pp. 411 – 424, 2016

S. Varun Kumar and H. S. Mukunda, Aluminized composite propellant combustion modeling with heterogeneous quasi-one dimensional (HeQ1-D) approach, Combustion and Flame, 192, pp. 50-70, 2018

20.4.5. Afterthoughts

I had mentioned earlier that the idea of working on the Oorja stove for my thesis bothered me. I wanted to do something in propulsion. That my colleagues were studying 'outstanding' and 'difficult' problems in propulsion contributed to this feeling. In retrospect, I am happy that I chose a problem that I could solve. This I believe is the most important thing (while writing this I am remembering the reply letter from Prof. Richard Feynman to his Japanese student Dr. Koichi Manom). That assigning a problem that a student could solve is of utmost importance is something that HSM must have known all along! I believe he has an excellent sense of figuring out the right problem for a particular student. Once he does this, the pathway is clear - he

pushes the student to tackle the challenge while continuously raising the bar. The longer you keep up, the better you get at solving problems. While writing this, I am remembering the writings of Carlos Castaneda about his apprenticeship with Don Juan - books brought to my attention by none other than HSM. I believe that I have been keeping up to the challenge till date and that is the primary reason for the continued strengthening of our relationship.

20.5. R. N. Narahari - my links

I joined IISc on 26th March 1981 for a temporary Admin Assistant and got into a permanent LDC post on 17th July 1982. The first placement was in the Department of Management Studies, post regular post, I was transferred to Centre for Scientific and Industrial Consultancy (CSIC for short) on 11th March 1983.

CSIC was a vibrant office and iconic then – be it S & T related activities, visit of dignitaries or infrastructure at IISc. Prof MN Srinivasan (MNS) was one of the great personalities I had met at IISc with great qualities to nurture and nourish HR. The actual business of CSIC (serious discussions with the concerned faculty members over the project related activities) would start post working hours stretching some times to 10 pm. Of course, the meetings would be over evening special snacks with coffee/tea. During one such discussion, I encountered Prof. HS Mukunda (HSM). I should confess that, then, I never imagined that he would play a crucial role in my life!

In March 1985, MNS had gone to Bombay-Ahmedabad for his usual trip to one of the foundries of Mr Shah for a referral work. During such visits, MNS would call CSIC and exchange notes on various activities though there would be an in-charge Chair. Prof MNS had agreed to deliver a keynote address in one of the Karnataka Industrial Investment Development Corporation (KSIIDC) meetings involving industry in the last week of March 1985. MNS entrusted me a task of preparing some key data for the talk and prepare a draft for the purpose. The KSIDC event was just a few days away and I was frantically trying to get in touch with MNS.

I got really worried, as surprisingly, that year, his visit went on for longer than scheduled period and it was not possible to reach both at Bombay & Ahmedabad (the land lines, of course). I informed KSIIDC office that if not Prof. Srinivasan, another identified faculty member would deliver the key-note! I started seriously hunting for a replacement and approached a few, however, whomever I had approached turned down the offer. I approached Prof HSM over phone and explained to him the crisis CSIC was in and would he be able to deal with it. I was somewhat afraid, since HSM had the reputation of being very strict, swift and rather would speak to the face! He asked me as to what he was supposed to speak? I told him immediately, with utmost innocence and commitment that, Sir, if you just speak whatever you generally discuss during evening meetings with MNS, the same would suffice! To my surprise, he laughed and said, he can consider, provided there is sufficient material (data/information) for the purpose. I told him, that I have a ready draft material. HSM said he would come down to CSIC in next 8-10 mins, peruse the information/data. He drove down to CSIC Office in his two-wheeler in less than 6 minutes, inspected the draft, corrected/suggested the modifications and said, collect the transparencies on that evening and would deliver the keynote, with the talk scheduled for the next day at 11 AM. I immediately called KSIIDC office passed on relevant information.

Indeed, a happy ending and an unusual encounter!

20.5.1. Working with HSM - Chairman, CSIC

When Prof MNS was moved to the Tower building as Chief of Admin (equivalent of Advisor) in late 80's, he continued as Chairman of CSIC for a short while. Then, Prof HP Khicha was appointed as the Chairman in 1988-1989.

Subsequently, HSM was appointed as the Chair CSIC in 1989. Perhaps, because of previous encounter, he was especially close to me. He tried various new approaches at CSIC for outreach and promotion programs. For the purpose, a Special Committee of Faculty members was formed to identify some of the best, challenging and interesting consultancy projects, to help prepare faculty profile of IISc. At CSIC there were two major Committees – Advisory and Management; eminent members drawn from Industries, IISc and other Institutions for the purpose served on the management committee. A detailed statistical graphs/tables would be prepared (manually) for reporting to the committees and so data was available in some form. I was seriously involved in compiling the data for the purpose. The Special committee amply used these statistics for the purpose of picking the best, challenging and interest Consultancy Projects. I used to coordinate with the committee. The committee chose close to a dozen projects. Based on the findings, it was decided to publish a one sheet leaf-let – Resources-Skill-Technologies from IISc (title suggested by the designer) – a first of its kind. The first few themes were – Cryogenic containers, Stabilised mud blocks, Gasifiers, Aerodynamics, NDT, Water tunnel etc. The task was entrusted to me. The whole effort was a runaway success.

Creation of SID: During 90's another major initiative of the Institute was to create a Society to cater to the needs of various other R & D institutions of Instrumentation equipment (perhaps due to paucity of foreign exchange, conservation of exchange also affordability for Indian R & D organization?). HSM spearheaded the activity at the Centre and task of collecting the data from IISc faculty members was entrusted to me. I prepared a questionnaire for the purpose and collected data with one-one meeting personally from 400 members.

The task of registration of the Society for Instrumentation Development (SID – original name) was entrusted to me during 1990. 50% of my time was officially spared for SID activities. To start with more than half a dozen instruments were identified – Oxygen Sputtering Systems - Prof. S. Mohan from Instrumentation Unit - ISU, Higher Pressure Cells - Prof. S. V. Subramanyam, Dimond-edged Saw - Prof. Vikram Kumar and Crystal growth Apparatus - Prof. SV Bhat all the three professors from Physics, Mass Bauer Spectrometer from SSCU/MRC and more. Single page leaf-lets were prepared on the chosen technologies for the promotion. For the purpose, I had to closely interact with all the technology people to understand and coordinate various activities of the Society.

In 1991, HSM requested the Director to let him withdraw from the chairmanship of CSIC perhaps due to other administrative responsibilities. Though his formal relationship ended, I continued to interact with him for SID activities.

20.5.2. My links with CGPL

Recognising my keen interest in new technologies, HSM asked me to learn a bit on IISc gasifiers! I spent a little extra time beyond 5.30 pm at CGPL to pick-up a little more knowledge on the working of gasifiers, various biomass feedstock for the gasifiers, site visits, preparation of Detailed Project Report and so on, however, superficial it was.

I got a call from HSM to meet him at the CGPL (Lab for short) to accept a challenge! I met him and he said, I should pick-up a file from KSCST concerning – 100 kg/hr gasifier at Navodaya School, Tumukur and take a look at it. Further, he said, due to some reasons, the gasifier was not functioning, perhaps due to some management issue. I was assigned to take care of it and make sure that the gasifier is put on working mode. I accepted the challenge and before proceeding to the site (Navodaya School) I learnt the gasifier operation, after a few days of theoretical study of slides/ presentation and explanations in person, I was confident, I could give a try and accepted the challenge. I had to a make a few visits to the plant, assess the situation, did a couple of meetings with the DC (Tumukur) who was the Ex-officio Chair of the Tumukur Navodaya School who gave directions to the principal at the school to cooperate with me to run the gasifier. I could run the gasifier in 3-4 days and demonstrate the result to the principal and reported to the DC, KSCST and others on the issue. The gasifier was functional after a month's struggle, sorted out management issues related to biomass supply, processing and operation of the gasifier. Fortunately, I encountered, a smart operator in Mr Channakeshava (who is now working at CGPL, IISc) ran the system for a reasonable time.

With this, my association with HSM and CGPL became part of my routine at the Institute. I participated in various activities of CGPL and became one of the teammates. Some of the tasks I closely associated at the laboratory were: (1) briquetting/pelleting powdery biomass – identifying and out-sourcing the work, (2) site visits and preparation of DPR (draft) especially for drinking water (BWSSB), major dams in Karnataka were visited along with KPCC Engineers, Bethamangala water pumping Station (KGF) electrification of water pumping stations, Mandya District and so on, (3) Solid waste management through gasification – Hubli Dharwad Municipal Corporation project, Various Waste Management systems in Bangalore and (4) Electricity through Gasifiers for Milk processing/storage facilities of KMF – Bangalore Dairy and Anekal plants.

A set of patents held by HSM and his colleagues are the major (~80%) Tech transfer/Royalty income generators of IISc. A separate program unit under the SID (in its new Avatar called Society for Innovation and Development) was created to handle CGPL projects. After some time, due to rigid procedural aspects, there was a need to create an exclusive system called Society for Advanced Energy Technologies (ABETS). The coordination work of registration and other aspects were entrusted to me. I was also drawn into almost all promotional activities of CGPL – be it publication, patenting, organizing technical events a few promotional films (quickies) were produced. In fact, after HSM withdrew from his position (December 2003) his involvement in the research activities intensified. Around 2014, when he had shed all formal responsibilities at CGPL, he still continued his research activities briefly at CGPL, but largely at Jain University and came out with a Clean

Continuous Combustion Devices (CCD) from 1-1000 kg/hr systems. He thought of creating a Section 8 company for the promotion of this new technology and started a company called FEAST – Foundation for Energy with Advanced Sustainable Technologies and got registered in 2015 with me as one of the Directors.

In my long-standing interactions with him at IISc, it appeared to me that as an individual, he was quite humane, gentle and concerned at times and also sharp and firm at other times. Also, it was clear to me he believed in empowering people rather than simply solving a problem for them. After a few years of my association him, he would utter that my qualification (graduation) is not commensurate with my knowledge! On many an occasion, he would coax me to purse higher studies. I used to handle IISc's patent related work at CSIC in 1996 and in 2002 when I came across a course PG Diploma in patents offered by NALSAR-pro, Hyderabad, he encouraged me to enrol (IISc sponsored my candidature). I was apprehensive about getting through as there were many young lawyers and other professionals enrolled for the course. To my surprise when the results were announced, I stood in the second place out of hundred and sixty all over India. This gave immense pleasure to him and pushed me to do my masters and then a PhD! His efforts of mentoring me, advising me and supporting me has continued all through……

Nearly 5 decades of association – growing stronger and stronger - with my dear HSM being for sure, an exciting encounter in my life.

REFLECTIONS ON LIFE

21.1. The prelude

Traditional upbringing that I came through had its positive points – devotion to scholastics and being respectful of the scriptures that led me to trust broad understanding that filtered into me from various sources till I was 21. Upsetting of several thoughts took place with Sri. Poornananda tirtha swami who gave lectures on Vedanta, Bhagavadgita and Yoga Vāsish□a over several years at Bangalore between 1965 – 1969. His more-than incisive statements led to intensive discussion amongst colleagues and self-examination of the truth of scriptural writings.

21.2. Why did I withdraw from IISc before superannuation?

I had several positions at the Institute over the next thirty-four years. In each position, I wanted to do something new and creative. This would go on for a while. Once the routine activities began to overtake creativity, mind would become restless. Combustion research at the laboratory would begin to exert greater pressure demanding attention and presence. It almost always happened that when I was to go to a specific office, the mind would create a conflict and I would submit to institutional demand of attending the administrative chore. Beyond a point, I would decide, this much was enough and I must move on. In all the offices I held, I requested the then director to let me go which was agreed to. This gave me experience of “death” of sorts. Each time, the mind got freed. After sufficient time, almost all offices seemed dreary in my mind. I had taken upon myself the responsibility to write a book on chemical propulsion, a subject I had taught and practised for over dozens of years so that the special things that I had learnt should become useful to others. I was turning sixty around Jan 11 2004, even though official I would turn 60 in May 2003 (simply because my father had set an advanced date as the birth date to enable my admission to the school). Things in my mind on questions of existence, science and spirituality about which I had read a whole lot and was reading not necessarily scriptural writings, but scientific and spiritual aspects related writings. I had attended a talk by Roger Penrose in 1996 at IISc and was influenced by the fact that he wrote about consciousness in his book “Emperor of the new mind” something that I thought was very interesting simply because he seemed to indicate that quantum mechanics had something to do with consciousness. I had tried reading occasionally, but was dissatisfied with my stop-start approach to studying something serious. I had spoken to Prof. Pashupathi, a physicist from the centre for theoretical studies (of which Prof. E. C. G. Sudarshan was a part) to examine the book and hold some discussions with interested physicists and others. He dismissed this perfunctorily and therefore, I decided that I needed to do this on my own in terms of synthesizing the relationship between consciousness and science at a pace that I should also internalize these findings. It was this compelling thought along with the need to move away from classical activities of an academic institution that led me to seek withdrawal from the Institute about 18 months before formal superannuation. Also, it would help me strengthen my mind in feeling that "I" had dropped the role as a Professor. My professorship would no longer be a crown and I could discard it since I would not be in the campus any more. The joy in anonymity was also something that I wished to experience. And consistent with Don Juan's teachings, this would help erase "personal history" (in my mind).

21.3. Interesting things after moving out?

Both myself and my wife visited Rishikesh, stayed in Shivananda Ashram for a month in july 2004, and in between went to see Yamunotri, Gangotri, Kedarnath, and Badrinath. It was a bit of monsoon season with occasional falling rocks. The journey was perhaps, hazardous, but wonderful till we were going to Badrinath. There was a land slide in between and it appeared like we could not proceed for a few days. Therefore, the journey ended here. The following year we went to Badrinath. We walked and walked around to go towards Mana, Satopanth. While on a tourist-like visit was well completed, the awe-inspiring and intimidating environment was something to remember for a long time, I did not get across to any person who appeared far beyond my perception. It was often put down to my destiny and I had no regrets accepting it. Over the next three years, we visited Advaita Ashram in Mayavathi, Dharmasaala, Jwalamukhi and other places in the Himalayas, staying at odd places for a few days in each location.

During this period I completed the reading of Roger Penrose's book, Emperor's new mind and Carlos Castaneda's books, A separate reality, 1971; Tales of power, 1974; The second ring of power, 1977; The fire from within, 1984; The power of silence,1987 and Journey to Ixtlan, 1991. These books had a profound influence on me. I may have read some of them several times. The books, Journey to Ixtlan and Tales of power contain wisdom that I find I can still reap by re-reading them. A mixture of mysticism and logical reasoning of human behavior, very non-intuitive in many parts has pushed me to moments of exhilaration having seen "round-the-corner", and several moments of self-doubt and depression of having not measured up to myself.

The parallels with scriptural writings were significant. The idea of "erasing personal history" was about the same as being a "sanyāsin" and the idea of stopping the internal dialogue is a different way of expressing a meditative state. Two concepts of "tonal" and "nagual" have been discussed extensively. While there are no direct links to such ideas in scriptural writings, these may be thought of as a way of getting inner poise. There are many statements in the books which appear original in the way of expressing ideas that are not vastly different from scriptural writings. For instance, he uses the analogy of a hunter to describe how a person should be "A hunter that is worth his salt does not catch game because he sets his traps, or because he knows the routines of his prey, but because he himself has no routines. This is his advantage. He is not at all like the animals he is after, fixed by heavy routines and predictable quirks; he is free, fluid, unpredictable." The state of Avadhuta is somewhat close to this.

Talking to some people described as very advanced in spiritual pursuit, and reviewing these in the light of scientific thought and progress led me to a well defined position that using the mind more and more incisively, asking the awkward questions to one-self and seeking answers within the framework of duality could lead to progress in rationalization of ideas and thoughts much more than advocated by anybody else. It was not difficult to ask: Is what is stated in the vedantic texts internally consistent? Can we use results from modern physics and recent research into the functioning of the brain to clarify matters? And once the mind was opened up, it became easy to see stuff in a new light and obtain consistency and simple fits to observations! In fact, it became clear that one can reach say, the 95% point of internal consistency through logic and logic alone. In some instances when logic cannot proceed further, the conclusion was that matter must be left at that stage.

21.4. Buddha, Chandrasekhara Bharathi, and Ramana Maharshi

Do we need to be concerned about great men at all? The answer is Yes, we need to be concerned. Quite often people extol the virtues of seven sages (Vasishtha, Viswāmithra, and others) and all that they represent. Most of the writing that is on these sages and others of olden times is shrouded in history (or mystery) that we do not have a record of them as historical figures. If somebody brings out the details of some of them, it turns out that others claim several persons with the same name but different periods of history. We should let historians bother about these matters and even touching the subject will get one entangled if one is seeking truth of the matter.

Hence, we should look for historical great men. From this perspective if we list people who have sought truth for its sake to the exclusion of other aspects, we have Bhagawan Buddha, Sri. Rāmakrishna Paramahansa, Sri. Chandarsekhara Bharati, Sri. Ramana Maharshi, and several others. There are also others whose life history has been so distorted that it is difficult to decipher the truth from the writings even after filtering some excessively worded statements. If we take the life of any of these people after they have realized there are descriptions available of their life that I consider very instructive. All of them have conducted their daily lives in ways that are not special; yet, they were special. I shall address three of them here.

The way Siddhartha evolved into Buddha is very relevant to many (like me) because he went through the early part of the life as a very ordinary person with a family, however keen an observer or thinker he may have been. If his life had ended along a course similar to what it was till the time he made a radical departure in his youth, history would have forgotten him. The fact that he spent the next seven years in a single-minded way to the complete exclusion of anything else to seek answers to fundamental questions of life distinguishes him from most seekers. I suspect he was also basically very intelligent (the word used in the traditional sense), something that is not described in any detail in any well researched history on him. I infer this because, even though there were several practitioners of Vedanta in his period, there must have been too many involved in the practice of “isms” rather than the core of Vedanta and there was not any “core” stuff that he could be deeply respectful of. For him to pursue, ability was needed to turn away from the unsatisfactory, when really, the pathway to the satisfactory was not clear; this needed intelligence apart from strong instinctive feeling.

I am emphasizing the aspect of intelligence since the discriminative ability is not always instinctive unless a person has already grown internally and the noise in the mind is very small. Hence, for the uninitiated, intelligence has a strong role. The principles of Buddhism evolved even in his life time quite substantially. Even later, there were several schools of Buddhism that evolved in India, Tibet and other parts of the World. Buddha had a large number of disciples, some of whom had evolved nearly as deeply as he had. His disciples went about preaching the Buddhist principles in India and various parts of the Eastern World – Tibet, Srilanka, China, Myanmar, Cambodia, Vietnam, Thailand, Japan, and other countries. In most of the east Asian countries, it has a strong foothold even today. It has also spread to the West and most large cities in Europe and America have Buddhist centres. Many people are moved when they read the Buddhist teachings. The principal teaching is to conduct a life in a manner that one is at equilibrium with oneself all through the life. There are several working rules and guidelines that provide input to day-to-day life [Thich Nhat Hanh, Old path white clouds, Walking in the footsteps of the Buddha, Full Circle, 2002 contains a very readable account of Buddha written with restraint and sobriety].

Chandrasekhara Bharathi grew up as a child (named Narasimha Sastry) in a family that had lost thirteen children born earlier to him either at birth or at a very young age. The family depended much on him as the lone surviving child in their family and also an improved living standard that could be obtained by modern education and the concomitant benefit of a secure job. He was into traditional modern education in the early stages and was into Sanskrit education later. At a young age of 20, he was drawn into the Sringeri mutt as its head with somewhat-reluctant parents accepting this situation. Coming from poverty, being shy in temperament and with demands of being beholden to others who took care of the daily needs of him and his family, it was difficult for him and the distinguished people around in the Mutt to reconcile to his elevation as the head of the Mutt. Surely, the wisdom and foresight that the earlier head of the Mutt, Ugranarasimha Bharati is to be recognized because this choice of his was not the one anybody else had even dreamt of.

Even as the Sanyasin-head of the prestigious mutt, he continued the learning of traditional Shāstrās under the tutelage of several scholars. Soon enough, he determined that his role would be more appropriately dealt with if he chose the path of contemplation and meditation. This he did even though as the head of the mutt, he had to discharge the religious role to secure greater strength of devotees and so, prosperity to the mutt. His life towards self-realization was tumultuous and he was suspected to have gone “insane” and efforts were made to send doctors from the National Institute of Mental Health and Neuro Sciences (NIMHANS), Bangalore to have him treated. Such acts resulted in strange experiences to the doctors concerned who had to return without even examining the patient. During this period of tumultuous behaviour, he was involved with himself and had no concern for the surroundings. Subsequent to this period, he is supposed to have achieved a state of inner poise noticed by most around him or those who visited him. Conversations during this period were brief, instructive and effective. There were many who benefited from his advice and directions in life. Some were blessed as well. There is an important message that can be derived from his life. He was not present on several occasions during the period of festivities even when an appeal was made to him that the people might feel blessed by a look at him and as to why he is denying them this simple gift. He responded to this appeal by saying that people come to him with many wishes to be fulfilled. How was it ever possible to conceive that all their desires be fulfilled? Each person carries along with his past and he had no desire to give false impressions to individuals. If somebody or some people have serious questions on the spiritual path, he would always be willing to speak to them and he was sure they would benefit by him. This must be compared with the impression created by several modern-day Godmen who would not hesitate to indicate that they can change the lives of people and remove their sufferings.

Also that they can change the society by mass training camps and some had gone even to the extent of advertising the possibilities of contracts to reduce the wrong-doings in the society significantly (Maharshi Mahesh Yogi). This is truly surprising because over the last several thousand years, the average level of morality has not altered a whole lot, the man-created or nature-created sufferings have gone on unabated with several ups and downs and no Godman has ever changed the society. It is important to realize that changes can indeed be made; but the scale in the area of spirituality will indeed be small or moderate, because the World was and will be about the same on the average.

A critical and deep appreciation of the character and his personality has been provided by Sri. S. K. Ramachandra Rao (see his book in Kannada language – Sri. Sharada Peethada Manikya). It appears that the overall conduct of his life can be better described in terms of an Avadhūta. Clearly, intensity of pursuit has been the strongest visible feature of his personality.

[Sri Shaaradaa Peethada Maanikya (in Kannada), Kalpatharu Research Academy, 1981; Avadhuta (in Kannada), Gayathri Book Co, 2002; R Krishnaswamy Iyer, Dialogues with the Guru (Sri. Chandrasekhara Bharati), Chetana Limted, 1998]

Ramana maharshi was an ordinary student called Venkataramana until a strange experience overtook him at the age of 16. There was no indication whatever of this transformation in him prior to the event. The death experience that overtook him caused an immediate transformation. The next several years that he spent at Tiruvannamalai in various places – a cave in the Arunachala hills and a cave like temple in the main temple at the town that seemed to have been aimed at establishing himself in the evolved state. Subsequently when he was established in the Ashram, he could switch himself into that state very quickly. Unless the circumstances around him seemed conducive for him to enter into a state of duality, he preferred staying in that state. As to whether it is Savikalpa Samadhi or Nirvikalpa Samadhi, as appears to be a subject of discussion, seems not as relevant as the state though very near, is very far for most. Hundreds of people met him, substantial number stayed at the Ashram and a large number were influenced by him. He never moved out of the Ashram during his life despite entreaties by several devotees inviting him to come to their town, or their home. He seems to have communicated to many a devotee more in silence than in words. His single consistent answer for any question on the way world was, whether something should be done to improve it and any such related matter was that one should understand oneself first before embarking on doing such things in the world. His simple direction was to enquire "who am I" and delve deep in contemplation. Rest would follow. He did not emphasize yoga or other methods as necessary routes (he did not decry any either). There have been indirect criticisms of these by other modern-day messiahs indicating that the simple approach of asking oneself "who am I" is inadequate, and conscious efforts are to be made to overcome the "Vasanās" – the past attachments. In such matters, there is no reason to expect that the prescription of the kind provided by Ramana Maharshi is incorrect, since the intensity of the application to the suggested approach itself could cause changes in personality over a period of time and the actions to relinquish the past attachments could happen in an organic manner.

He displayed during his later life at the Ashram certain aspects that seem puzzling. His devotion to the Arunachala – the hill, was so intense that he thought many great beings lived here over times and on the planet a similar place must be present on the opposite side of the Globe. In fact, he would ask Major Alan Chadwick to locate the map of the world and show him the location. He was told that the opposite side of the globe was sea, he seemed dissatisfied. He ensured that a Samadhi was built for his mother and showed deep interest in its completion. The puzzling part is that when the core of the existence was reached, when the unity of the diverse world was what he was, when the entire world was his own, why should such strange likes appear in his mind is quite unclear [Sadhu Arunachala, (A.W. Chadwick), A sadghu's reminiscences of Ramana Maharshi, Sri Ramanashramam, 1994; Talks with Ramana Maharshi, Ramana ashramam, 2003]

21.5. Contributions of Scientific studies to spirituality

Spirituality is a subject concerned with deeper universal questions of one-self and life beyond the limits of religion that is tradition and rule bound. Science is concerned with questions of observable world in all the deepest possible sense and obviously far outside of religion. Science is practised by people of all religious faiths and the conclusions they come to based on theory and experiments applies to people of all races and far more, all the species in the universe. The theory (or experiment) prescribes the limits of applicability over the species-space-time domain always wanting to look for generality in applicability. Since spirituality is concerned with matters within one's mind, it is often stated that where science ends, spirituality begins.

This is playing with words and in reality whether you think of “science” or “spirituality” you have to use your mind. When examining nature outside of one-self common to all people in many ways, the contemplation is of the external world, in fact, the issues of the external world are modelled in the mind and examined. And this examination needs deep contemplation to resolve paradoxes and conflicts that nature presents. Many a time, this degree of contemplation can be no different from resolving internal human complexities of ideas: to aspire or not to aspire, be ambitious or be contented, imposed unhappiness and joy all of which are the stated concerns of spirituality supposedly outside of science. Whenever such observations are made, it appears that the meaning of “science” is misunderstood. Science when interpreted as a systematic approach to study of questions seeking validity of resolutions at as many stages as possible appears applicable to the study of internal factors as much as external. And mind usually treated as a single amorphous entity is now broken into simpler activities inside the brain and resulting perceptions. Each of these activities is examined through various new non-invasive tools. These have shown very many interesting aspects.

Scientific studies on meditators are fascinating and form an interesting study on brain related functions. Studies on heart functioning during meditative practices have been conducted on Swami Raama (can be obtained on youtube). These have shown how he was able to control involuntary functions by using yogic techniques. Two points on the palm showed a difference in temperature of about 10 $^\circ$C after he went into his yogic trance. He also showed that the heart functioning could be controlled over durations of time without any alteration in the day-to-day activities.

Extensive brain imaging studies of meditators (Buddhist being the largest number) appear to show that large scale changes occur in the brain activity during meditation (Matthieu Ricard, TED talks; Antoine Lutz, Lawrence L. Greischar, Nancy B. Rawlings, Matthieu Ricard, and Richard J. Davidson, Long-term meditators self-induce high-amplitude gamma synchrony during mental practice, PNAS November 16, 2004 vol. 101 no. 46 16369-16373).

These processes are supposed to lead to people with much less stress and hence "happiness" [https://www.frontiersin.org/articles/10.3389/fpsyg.2013.00973/full]. The study has got expanded into studying consciousness using subjects who are in deep coma or anaesthetised and many revelations that have therapeutic value have got uncovered [https://www.nature.com/articles/d41586-019-02207-1]. These are at one end of the spectrum.

More importantly, Chris Frith (Chris Frith, The making up of the mind, Blackwell Publishing, 2007, p. 69) and Oliver Wolf Sacks, Musicophilia, 2007 [https://en.wikipedia.org/wiki/OliverSacks] has a have presented extremely interesting aspects of the functioning of the brain concerning the vision and auditory functions. The centre of freewill was also examined by allowing people to make a range of choices and locating the part of the brain that lighted up under these conditions. Francis Crick and Christoff Koch have examined the question of consciousness within the framework of brain function (through neuronal connections) and argued that many of these questions are within the ambit of scientific study at this time (Francis Crick and Christoff Koch, Cerebral cortex, v. 8, pp 97 – 107, 1998).

21.6. Studies on Fate/Freewill and Reincarnation

The really most crucial result from such studies have come from Prof. Bejamin Libet. He specifically showed from very simple experiments that the brain activity precedes the awareness of an action by about 300 ms. Thus, any claim to conscious decision making is to be understood to be "presumptuous" (B. Libet, Reflections on the interaction of mind and brain, Progress in Neurobiology, v. 78, pp. 322 – 326, 2006). There are other experiments in which the actual action that gets taken (by the brain) bypasses our conscious awareness completely (stick reaching experiments as well as Roelof's illusion, Chris Frith, 2007).

Thus, the most important result from this study is that an unconscious process precedes the conscious decision making. All claimed conscious decisions are in fact projected suggestions from the unconscious. This implies that whatever happens is already decided! Sounds strange and difficult to accept or even believe. This has been discussed, debated upon and lectured upon a whole lot with conflicting impressions. One of the reasons that speakers on spirituality (many - Jaggi Vasudev, Sri Sri Ravishankar, and others) perhaps feel that the fact that asserting that fate prevails even at microscopic levels will lead to social lethargy and inactivity. This is simply presumptuous. Almost any individual speaking with bravado that he/she will go against the fate is only impelled to claim so because of inputs from the unconscious since it precedes the state of awareness or conscious act. It requires care and effort to appreciate this within oneself by a self-examination of life in one's own quietude. That this does not mean suggestion for inactivity is also something that requires different consideration. The fact that we are all driven by “fate” appears in a different form in Calos Castaneda’s book “The active side of infinity”. Don Juan while speaking to Carlos Castaneda says “……What put you and me together,” he went on, “was the intent of infinity. It is impossible to determine what this intent of infinity is, yet it is there, as palpable as you and I are………. and to acquiesce to it without any further ado. For sorcerers, there’s no pondering, wondering, or speculating. They know that all they have is the possibility of merging with the intent of infinity, and they just do it.” (The active side of infinity, 10th book in the series by Carlos Castaneda, p. 37)

One point brought out by Roger Penrose in his book (Emperor’s new mind) is that many important discoveries that have arisen in Mathematics and physics have come about when the concerned researcher was not even thinking about the subject indicating that these have arisen in the mind spontaneously. The examples provided are of Henri Poincare, Hadamard, Mozart and that of himself. He argues that the first thought or inspiration comes from the unconscious and the conscious mind deliberates and accepts it or rejects it before the matter is concluded. I wish to argue that the link between the subconscious and the conscious is always continuous. The conscious mind is either absent or very weak during sleep. Thus, even during wakeful periods and interaction with the rest of the world, the interactions will be present and if the conscious decisions are ascribed to the unconscious, it cannot be argued to be incorrect and the signals from the areas associated with unconsciousness related areas will be present even during wakeful period.

My own personal experience over the last twenty years in particular has been that during the resolution of conflicting experimental evidence on combustion and fire research has been that when I wake up on many days, the thoughts that arrive soon after, appear to contain a new direction or a partial resolution. Only on some days, I have had the complete understanding of the correct solution. This would happen after several days of mulling over the data and a theoretical framework that could support the data. I guess this experience is not unique. Actually, many people not necessarily in the scientific profession have an understanding that some unsought special event in their life changed their life. It is not always the traditional view point that when one prays the Lord for something to happen, it would happen; it might or might not. But as a part of historical analysis, the role of something "beyond" in affecting our lives is often times experienced. Some of these are accepted even to an exaggerated degree in communities in the east rather than in the west.

The debate about the existence of consciousness and if so, what would it be is a subject of intense discussion at conferences and there appear to be polarized views on the subject. This is not surprising because the issue of defining consciousness within the scientific terminology is indeed very subtle. One extreme position is that every object, organic or inorganic, molecules and fundamental particles including have consciousness. This is consistent with the Vedantic thought: Sarvam Bramhamayam Jagat - World is all and simply Brahman - an equivalent word for consciousness, a thinking process that is at least several thousand years old. An interesting view point of one of the very distinguished scientists Christof Koch, the chief scientific officer at the Allen Institute for Brain Science, said that on the basis of his recent research he thought it wasn't impossible that his iPhone might have feelings. Many discussions are taking place and a recent summary is provided by Emily Sohn in 2019 *[Decoding the neuroscience of consciousness, https://www.nature.com/articles/d41586-019-02207-1]*

In order that we progress further, I have thought it vital to bring in the subject of reincarnation. A very distinguished scientist, Ian Stevenson spent a large part of his academic life exploring the possibility of reincarnation. Tucker (2008) studied over several hundred cases from a dozen countries, both east and west and drew conclusion that no explanation other than reincarnation would fit the observations. When doubts were raised regarding one set of cases, he re-examined the cases and showed that the study was indeed correct. *[Tucker, J. B., Ian Stevenson and the case of reincarnation type, J Scientific Exploration, v. 22, pp. 36, 43, 2008; Stevensom, I., Pasricha, S., and Rice, N. M., A case of possession type in India with evidence of paranormal knowledge, J Scientific Exploration, v. 3, pp. 81 -101, 1989].*

The key question that has not been answered is as to how the transfer of one life is transmitted after death to another life. I have not read anywhere the posing of this question itself. The only hypothesis that would make sense would be that a basic field of consciousness carries with it the code related to the progress of life through various birth cycles. It is not impossible that in large number of cases, the life cycle repeats within the family - a great grandfather appears again in a new life form. This is the reason that the idea of child prodigy becomes possible. Bhagavadgita has a stanza where Lord Krishna states that he knows all his past lives. Thus, the field of consciousness creates various inorganic and organic life forms that change over time. The expressions at the macro-scale show a wide variety that is expressive of consciousness and can contemplate on it and express it as well the inanimate objects like stone, metals and a range of observables.

What would the meaning of life in this context is the question. The only answer that can be given is that there is no meaning, certainly over cosmic time scales. They are meaningful only in the sense that once born, the life must be gone through pleasantly and towards this we have the enormous infrastructure of ethics.

APPENDIX I

The US trip – 1984

A1 The departure

After making hectic arrangements for the journey, all the five of us [myself, B N Raghunandan (BNR), P. J. Paul (PJP), Udupi Shrinivasa (Udups), H. K. Narahari] managed to leave our homes and arrive at the Bangalore airport (at HAL) by 5.20 pm on the 10 August 1984. Security regulations were tough at the airport because of the bomb explosion at Madras (Chennai now) sometime earlier. Since some of us had reached earlier and I was watching the opening of check-in suit cases, I wanted to check the opening of the diplomat hand baggage. Oh! It did not open. I thought its number lock was set to the residence number, 309 from some time. Though I had some difficulty in setting it at home, I thought things would be fine. But they were not. It took the effort of three of us and 30 mins before the lock was broken open by a screw driver. Shortly afterwards we went through the security check and the number lock aligned itself to 309 and the diplomat suitcase became normally usable. The first forty minutes turned out to be a tension creating affair.

The journey to Delhi and the stay at the transit hotel accommodation and check-in at Kuwait airways for the Kuwait-London-New York flight was relatively uneventful. The change-over of flights at Kuwait has a three-hour wait. The onward flight from Kuwait via Greek islands and over Europe to London was very nice. We identified the islands and some countries on the way by the signatures of the land mass in the sea and the descriptions on the map.

The flight stewards on this leg were impolite and unhelpful and seemed to be uttering curses when requested to give vegetarian food. We had to manage with vegetarian elements of non-vegetarian menu. A film was shown on the flight. The stop-over at London – Heathrow airport was indeed refreshing. The airport was clean, well arranged and had so many directions that it was difficult to get lost. This is a feature we would observe all the way in the USA and European countries in the airports. En-route, we reflected on why the arrangements were so regretfully bad in our country. This part of the backwardness had very little to do with our economic condition. It had to do with the willingness to change, to help each other and particularly a new person, a feature not so common in our country. A related matter concerns the lack of easy availability of maps in any new town or city in our country. In airports/ bus stations/railway stations, there ought to be more maps available even on s small payment so that a newcomer can benefit by managing himself/herself without having to ask people around (thus lessoning the chances of being waylaid. etc).

The arrival at John F Kennedy international terminal at New York happened a few minutes earlier than the scheduled arrival time and the passage through immigration control did not evoke respect which we seemed to have acquired by the rush at the US consulate in Madras (Chennai now). The immigration control officer seemed casual and did not stamp the document properly. I had to remind him of the dates before he completed it. The acquisition of the baggage and passage through customs was even simpler than thought, because I had carried some possible objectionable food items like pickles and hot chutney powder (may be, it was my imagination). We did not get even a scant look. After we came out of the airport, we were met with by Mr. P. Venugopalan (of DRDL, Hyderabad) who had reached by an earlier flight and another person, Mr. Narendranath to whom we had written earlier. He was kind enough to fix our next day's journey to Detroit by a Piedmont flight (85 USD from NY to Detroit) and intended taking us to his earlier apartment in Brooklyn on 96th street. We decided to take the tube even though it was slightly risky at this time (8.15 pm). We managed to take a bus to go to the underground station area at 42nd street and bought 0.9 dollar per person ticket to board the train. The train was deserted and the platform had only one another person. We were reassured by our host that things are not "too bad". Anyway, in the next ten minutes, ten more people joined in and a well-dressed "big" policeman with gun, walkie-talkie and handcuffs walked in, saw around and was moving back and forth along the train. This was reassuring to travellers like us.

We reached the apartment after lugging the baggage for a short distance and got into the apartment of our host who was the friend of our friend (once-removed acquaintance). Three of us slept here and three others in the upstairs apartment. It took no time for us to get to sleeping – 24 hours had been compressed into 12 hours. The body had to adjust to this jet-lag. We got up at 4 am (local), finished the morning ablutions and went out to a restaurant nearby at 7 am for breakfast. The inevitable question of selecting vegetarian items for breakfast came up. Pancakes that are essentially thick dosas taken with syrup (with difficulty after a few morsels) was the staple food along with coffee. It costed 2.5 USD considered reasonable under the circumstances. We took a limousine for 25 USD for six of us to get to La-Guardia national airport. This airport was indeed large and has different segments for different flight operators and directions. We went to our counter and asked the front desk person to check us in.

A2 To Ann Arbor, Michigan

We paid the money at this time and got our boarding passes. We had to get down at Baltimore on the way spending an hour before the flight to Detroit. The airport at Baltimore was huge carpeted, clean and had large number of seats for transit passengers. The flight was during the lunch time and so we were served lunch. Since there was no formal vegetarian lunch, we had to make good with whatever vegetarian elements were available. We arrived at Detroit at 1.40 pm, collected our baggage by 2 pm and left in a limousine by 2.10 pm. We arrived at the University of Michigan, Ann Arbor, specifically at Stockwell hall by 3.00 pm. Our names had been entered and rooms allotted and ready. We had to enter our names and pick the keys and get to the respective rooms. We spent another fifteen minutes in our rooms and walked to Michigan League Hall about 0.3 km away for registration. After the registration, we met a large number of Indian and other friends and colleagues and spent time old time activities, exchanging notes on various matters. Our papers were scheduled for presentation on the first and the last days both in the evenings – 4.30 to 5.00 pm. The evening cash bar saw a number of people holding glasses of liquors and loosening. WE met Prof. Forman Williams for the first time and exchanged notes with Prof. Herman Krier (whom I had seen in the 1982 symposium in Israel), Prof. S. Okajima, Prof. H Tsuji, Dr. L Krishnamurthy and several others. After the dinner that contained a fair number of vegetarian items like salad, buns, fruits and coffee, we turned in 10.30 pm. Early morning saw us at breakfast at 7 am with a fabulous offering – so many fruits, mashed potatoes, pancakes, soft breads, cornflake, strawberry shake, and yogurt to choose from. The stay and breakfast costed us no more than 12 USD per day (cheap).

The daily routine consisted of attending the sessions from 8.30 am till 5.00 pm and other scientific discussions with specific people from 5 to 7 pm or so. Dinner would be at outside restaurant Mexican or Burger king. Burger king was a part of standard chain attached to most Greyhound bus stations, something that we made use of for our trip after the symposium. It has amongst other items, strawberry shake, salad-in-Peta (vegetables in a semi-circular bag of bread's outer cover), fried potato fingers, onion rings, apple pie, coffee with milk and sugar. I used to pick a few of these and finish my lunch/dinner/breakfast whatever occurred at a given point of time. On Tuesday, reached out to Mr. F. S. Prabhakar, a relative of mine and an ex-IISc faculty member who was staying at Jackson, 40 km away. Telephones with call collect facility helped managing the communication without having to spend dollars from our side. Meeting with Prabhakar was fixed for 12.30 pm on Wednesday, 15 August 84 at which time he came in a large car. All of us piled in and we went to French consulate in Detroit to get the visas for our France trip. We had to go up and down in high speed lifts in many buildings before we got the French consulate. We got our visas after explaining to them why we could not get the visas from India itself – due essentially lack of time between visas to US and Germany and the trip itself. We reached his house at about 7 pm. He gave advice on cheaper shopping options like at K-MART. We had also food at his home – excellent at that and returned to the university by 12 midnight. Thursday and Friday were busy days when we had to fix up our tour in the USA. We decided to go by Greyhound with journeys during nights and uncovered that it would cost 186 USD per person.

A3 Southwards - Washington DC

Accordingly, after the symposium ended at 5 pm (after our presentation between 4.30 and 5 pm), we left from our rooms to go to Ann Arbor bus station where we boarded the bus to go to Detroit where we caught the bus to Washington DC starting at 9.00 pm. We were advised in the bus itself not to move out too much for we might be pick-pocketed. And what more, if we did not offer money, we could lose our lives. We had burger king dinner before the start of the journey.

We reached Washington DC by 11.15 am on 18th August 1984. On the way we had breakfast at another Burger king on the way at 7 am. The buses had also rest rooms as they were called. They had wash basin and western commode. The travel by the bus appeared to us far more convenient and comfortable. After reaching Washington DC, I called up Venugopalan who had reached it by air on the previous night. He said there were some seats available at the International Youth Hostel close to Greyhound bus station. In the mean time I discovered that I had not received my baggage at all (the check-in red suitcase). Enquiries at the baggage counter indicated that they had not received it but hoping to receive it (in a manner not too different from what would happen in India). In any case, we walked about 100 m to the youth hostel and booked ourselves into it. Curiously, the place was no more than a km from White house and was a red-light area! We had bath and waited for Simha prasad doddabele (formerly from our department, IISc) to pick us up in his car for a short drive to Smithsonian Air and Space Museum. He discovered after the drive that there was no place for him to park his car. After dropping most of us he and BNR drove around for another hour and half before they could locate a place to park that was a kilometre away! In the meantime, we waited for half an hour, took lunch and began to wander around in the exhibition. Rocket engines of several kinds had been kept and some even in a manner integrated with the stage. Venugopalan and myself spent nearly four hours seeing everything. Finally, BNR and Simha showed up and we went together into the film “Earth” projected on a wide screen. The filmic value was high but content average.

We went about again in search of food in the evening at around 7 pm. While the hotel got located, there appeared no place for parking. After driving around for an hour, we located no parking area and so, we shifted to another hotel with Indian menu and got dropped back to the youth hostel. I had telephoned SMD (Prof. S. M. Deshpande, my colleague at IISc who was on a sabbatical at NASA Langley Research Center, Hampton, Virginia about 300 km from Washington DC) and he arrived on the 19th August 1984 around noon. Our friends went off to the visit of the Smithsonian Museum for natural history while SMD and myself talked and walked around the White house area. On the departmental matters. He suggested that I should also seek to become a senior research associate like him and he indicated that his supervisor, Dr. Phil Drummond is a good person and he would speak to him, etc. After the long conversation, he left for Hampton. Our friends came back from the visit to Smithsonian and we picked our baggage and walked towards the Greyhound bus station. In the morning, I had gone to the Greyhound station and insisted on seeing the manager and got him to let me make a baggage trace complaint. They did not seem much better, only a shade better than our Indian counterparts. Surprisingly, as it would turn out, the customer service people at the Greyhound stations were indeed courteous and helpful unlike the Washington DC staff. We left by Greyhound at 4 pm southwards with the next stop being Richmond where we arrived at 6 pm. Surprisingly, Udups who had gone to Virginia soon after we had arrived at Washington arrived at Richmond and got into our bus. We were happy to be together, again.

A4 Atlanta, Georgia

The journey to Atlanta through Charlottesville was long and tedious. We arrived at Atlanta on 20th August 1984 by 7.15 am. We then left Atlanta by 8.15 am and reached Birmingham at 10.45 am. After telephoning Venugopalan who had reached Birmingham earlier, the visit to Leeds got fixed. Mr. Teague and Mr. Mckenny came to pick us up from the bus station by about noon. We reached their office and works by 12.30 pm and had discussions till about 2.45 pm and came back to Greyhound bus station by 3.15 pm. We got on to the bus going to Atlanta by 3.30 pm bus and reached Atlanta by 8.15 pm. Telephoned Venugopalan at Ramada inn and arranged to have the stay there only at 100 USD for five of us. Next day (21st Aug) we went in the morning to Georgia Institute of Technology, met Prof. B. T. Zinn (whom I had seen both at the 1982 symposium as well as at Ann Arbor). Prof. Zinn arranged to have one of his Indian graduate students, Mr. Laxman to show us around the laboratories. Prof. Zinn himself appeared very busy in preparing some funding proposals as he indicated. Subsequently, we met Prof. E. W. Price and arranged to have a meeting with him at 2.30 pm. At this time, we were shown his laboratory and we had a long and profitable discussion with him and walked back to our hotel by 5.00 pm. On the way we had seen an Indian restaurant, had a nice dinner, went back our hotel, picked our baggage and took a cab to go to Greyhound bus station.

A5 Orlando- Disneyland - EPCOT center

At this place, we took the 9 pm bus to Orlando which we reached by 7.15 am on 22nd August. I telephoned Venugopalan who had reached earlier to check up about the arrangement for the visit to Kennedy Space center. Later we bargained with the taxi driver to take six of us to Tampa, Kennedy Space center, EPCPT center and drop us back at the Greyhound bus station for a total of 205 USD. We reached Kennedy space center by 9 am and saw around a large number of rocket engines and went on a tour of the island containing the Saturn V transporter, the total vehicle, the space shuttle launch pad and space shuttle transporter. We also saw some exhibits. By this time, it was 12 .20 pm (we had a brunch at 11 am itself) and we left EPCOT center then and reached it by 1.30 pm. EPCOT center is an evolved version of Disneyland that has many futuristic elements. We were told that this has come up in the last two years. We saw about half-a-dozen pavilions and found it very entertaining and educative. Most of the pavilions were put up by ATT (telephone company), General Motors and other reputed companies of the USA. In most of them, one stood in long queues to get into the transporter having three seats each side. When the transporter went in darkness would settle in. Then onwards, the sides contained most of the exhibits. It is in the creation and maintenance of these that a marvelous effort must have been put in. In one of the pavilions on energy, the entire auditorium split into two parts and was moved around giving in addition, a bizarre effect of early world creation and so on. A closer and perceptive examination showed that in some instances, some of the exhibits did not integrate with the theme, but the whole things looked gorgeous.

A6 New York

This visit ended at 5.30 pm and we drove back in the taxi to Greyhound bus station by about 6.25 pm and we took the 6.40 bus to New York via Jacksonville, Baltimore. This journey was 25 hours long with a few stops in-between and we relaxed into a drowsy state most of the time. We reached drizzling NY port authority terminal by 7.40 pm. I went to the baggage section and was fortunate to see my baggage there. Hugging the "lost" baggage came out, joined my friends and went by metro to reach 99th street, Broadway, Manhattan area after an arduous effort of an hour and a half. We went to a residence of a friend of Udups. That night we ate at a Chinese restaurant – rice and vegetables cooked in the Chinese way – frying in oil. The next day morning (24th August) we went by suburban bus (it accepted the Greyhound tickets) to Princeton. After a couple of telephone calls reached the Princeton University and went to the energy division. Discussed with a collaborator of Prof. A. K. N. Reddy and visited the laboratories and had a special lunch arranged for us. Then we broke up into two groups, one with the energy group and another with Prof. Forman Williams. After these discussions, we returned to NY.

The next day – 25th August saw us roaming around in the 45-52 streets, 5th to 10th avenues looking for gifts and souvenirs. We completed by 5 pm and returned to our residence by 6 pm. We had found that a sales shop in Lexington Avenue and 28th street in Manhattan and 75th street, 37th street (near Jackson heights station) in Queens having some dresses that could be bought for India. We went to this area bought dresses, ate lunch at "New Delhi hotel" and came back to our residence by 4.30 pm, packed our baggage and got ready to leave by 6.15 pm. Took a taxi and were driven through the Harlem area to JFK departure area of Kuwait airways. This took 25 USD, cheap for the distance involved. We finally left the USA by flight on the 26th August 1984 at 9.30 pm to go to Europe.