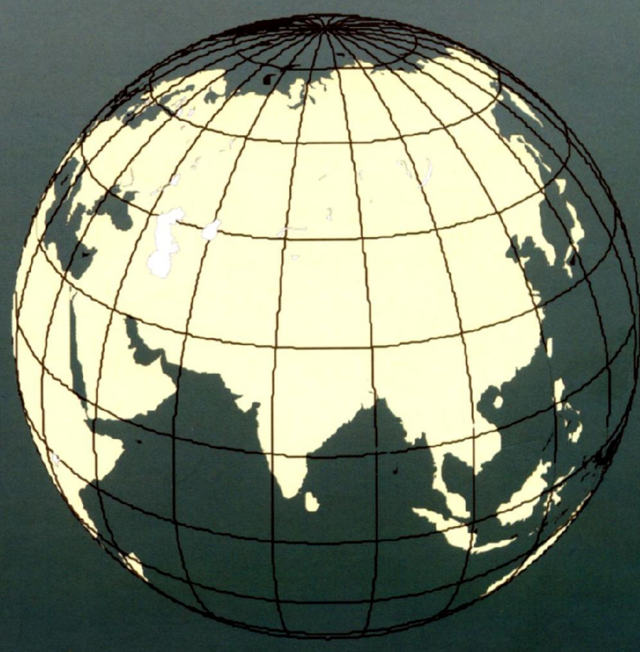
BIOMASS TO ENERGY

The Science and Technology of the IISc Bio-energy Systems



ABETS, INDIAN INSTITUTE OF SCIENCE, BANGALORE

Biomass to Energy

The Science and Technology of the IISc Bio-energy Systems

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Price : INR 500.00
USD 20.00

Printed at
Aditya Printers,
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Hanumanthanagar, Bangalore - 560 019
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Acknowledgements

All of this has been possible due to financial support from several agencies.

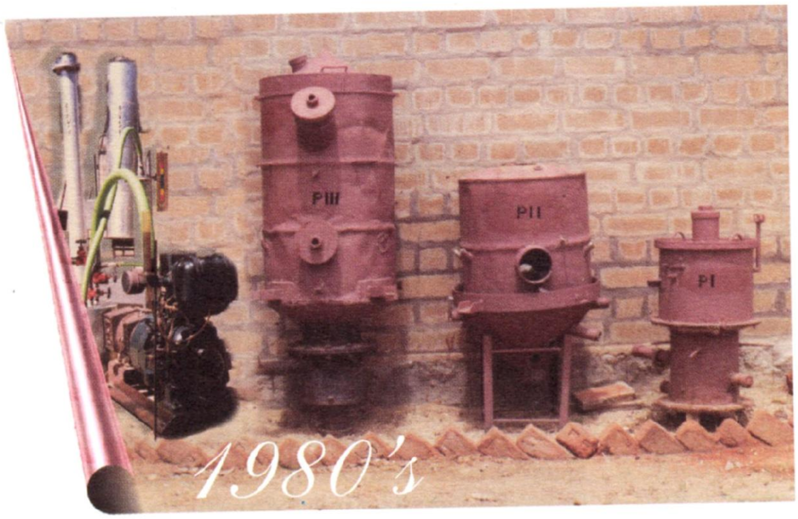
The Karnataka State Council for Science and Technology (KSCST) offered initial support under the leadership of Prof. A.K.N. Reddy, who was the Secretary. The Council for Appropriate Rural Technology (CAPART) and Rajiv Gandhi Foundation have both backed the Hosahalli village electrification project. The Ministry of Non-conventional Energy Sources (MNES)" lent Research and Development support, which was received under Gasification Action Research Centre and Program for ten years. Major project support is related to pulverized fuel gasification (Powdery Biomass Gasifier Project, **POBIG**), Strategic Development of Bioenergy (**SDB**), Advanced Biomass Gasification (**ABG**), as well as National Biomass Resource Assessment Project (**NBRAP**). The principal personalities responsible for the initial support from MNES are Dr. O.P. Vimal (late)and Dr. K. K. Singh, and later, Dr. K C Khandelwal. Sri. Ajit K. Gupta, Sri N P Singh, Sri A K Dhussa, Sri R S Rana, Sri. S S Bawa, Sri. R. D. Shrama, Dr. J. R. Meshram and Sri. Gangesh Upadhyaya have all lent support in recent times.

Financial support for the conduct of tests – Indo-Swiss test at Bangalore, India, Swiss-Indo tests at Chatel-St-Denis, Switzerland and on pulverized fuel gasification systems at Bangalore – have been received through Dr. H. Sharan, **DASAG**, Switzerland. Mr. Pasquale Giordano and his colleagues of **CCC**, Chatel St. Denis, Switzerland have also taken interest through the company Xylowatt to commercialize the technology in Europe.

Support provided by all the users of the technologies developed at the Indian Institute of Science is highly appreciated.

Prof. N. H. Ravindranath and Sri. H I Somashekar of the Centre for Application of Science and Technology to Rural Areas (ASTRA) collaborated on the village related work and Dr. H N Chanakya, has coordinated one field experiment related to irrigation.

M/s Yen Kay Gee (NKG) Consultants, through Mr. B. S. Venkataramaih and colleagues, were collaborating on the precipitated silica process that has been extensively tested in the laboratory. This process is being industrialized.

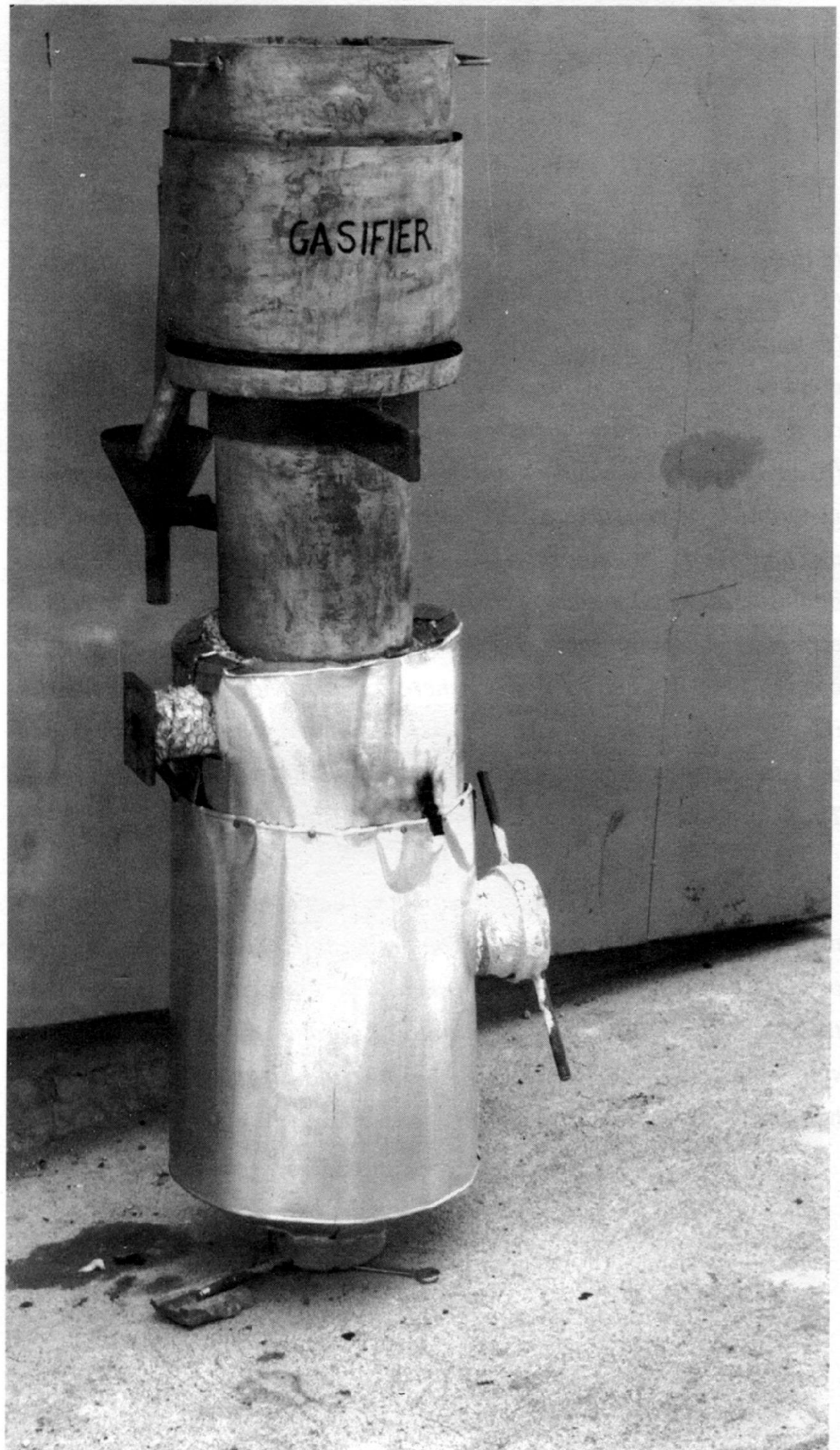


to

Preface

*At the **C**ombustion, **G**asification and **P**ropulsion **L**aboratory (CGPL), of the department of Aerospace Engineering, Indian Institute of Science has conducted work on bio-residue-based gasification for; (a) understanding the processes involved in the conversion of biomass to a combustible gas, (b) understanding the processes involved in the combustion of the gas with air inside the cylinder of reciprocating engines, (c) applying this knowledge to the development of the technology for power generation, (d) conducting field trials to appreciate field-related problems and improve the technology, (e) examining this renewable source of energy against centralized sources of energy and other renewables from the techno-economic viewpoint; and (f) creating a bio residue resource map of the country's bio-residues for power generation to provide for entrepreneurial initiatives in power generation. The laboratory has developed technology to sweeten biogas generated using anaerobic digestion route. The sweet gas is used in gas engines to generate electricity.*

The current status of gasification has been achieved after about 300 man-years of effort with about 60,000 operating hours on 12 systems of power level from 3.7 kWe to 1000 kWe. The gasification systems from 1 kg/hr to 850 kg/hr with operational duration on single gasification system exceeding 6000 hours in a year on an industrial system and 20,000 hours on a village electrification system.


GASIFIER

Contents

Executive Summary

This document describes the science and technology of modern gasification systems that can generate *ultra-clean gas* with high gasification efficiency for nearly any given biomass or non-biodegradable organic dry material. This enables the use of the gas for high-grade heat or electricity generation via reciprocating engines or gas turbines in dual-fuel mode or gas–alone mode. Details include the experience derived from field studies on industrial installations as well as those for village electrification. The use in various sectors helps in appreciating the robustness of the technology that has remained maligned from the mid forties due to bitter experiences of "tar" in the gas stream. The robustness has largely been due to the reactor configuration central to cracking tar and a special cleaning system that invokes a physical process to drop the last of all fine particulate matter back in the gasification island. It is the expression of the feeling of "having arrived" in the intrinsic gasification methodology that has resulted in the design of reliable plants – thermal or electric – that benefit in addition, from modern automation and control technologies to ensure performance *comparable to centralized power generation plants.*

The design of the reactor allows the use of fuels with high alkaline content that are prone to ash fusion due to the lowering of the ash fusion point. Fuels like sugarcane tops and leaves, coconut coir pith containing copious amounts of potassium are handled through reducing the superficial velocity in the packed fuel bed to a level that maintains the integrity of the ash in the pulverized form enabling a 'smooth' screw extraction process. Fuels containing organic non-biodegradable material like plastics have been tested at less than 30% content and the ability to restrict undesirable component like dioxins from chlorine-based plastics (like PVC, Poly Vinyl Chloride) within the gasifier island without emission into gas has been established. It is important to understand that classical closed top throat based design does not permit the above choice, nor does the idea of a simple open top reactor used by the Chinese for rice husk meet the requirement of minimizing the tar content.

The final configuration for the reactor resembles very little of its parent of the mid-forties. It separates storage of biomass as a part of the reactor, as in classical design of the mid-forties and devotes it only to the conversion process. It draws air from the top and from the sides permitting reburn of the gases, hence creating a second high temperature zone where tar cracking can occur due to the simultaneous action of heat and catalytic action of hot char. The bottom section has a vertical grate and screw extractor for the ash and perhaps some char. The choice of the screw system instead of grate arises from the need to extract much larger amounts of ash compared to what would happen with woody fuels with low ash. The first extraction of dust in the gas occurs in a cyclone. The gas may then have an indirect cooling system to extract clean heat. Subsequently, it passes through an ambient temperature ejector cooler-scrubber using water and chilled liquid ejector-scrubber before going through a very fine fabric filter. The gas qualifies for being ultra clean. The gas that goes into a furnace or an engine is sampled by bubbling it through a transparent clean solvent to enable the gasifier operator to be sure of the quality of the gas in terms of presence of tar or particulates. That the solvent remains clean and transparent hour after hour, day after day, gives innate confidence to the power plant operator that the engine or critical components of the control system in a thermal application will operate in a manner that he is accustomed to when using fossil fuels.

It is possible to operate the gasification plant running on coconut shells or wood chips with low ash content such that one can extract char about 5% of the throughput. This char has properties of activation directly or with thermal treatment. This product has a sale value that can pay or more than pay for the cost of the raw material.

In power plants – gasification or direct-combustion using rice husk, the residue after combustion has considerable carbon – typically, 10 % and amorphous silica, if the combustion process is handled with limited residence time at high temperatures. This residue is a waste and current uses are in brick making and cement industries; even so, the waste generation far exceeds current utilisation. Amorphous Silica is a valued industrial product that can be extracted from the rice husk char/ash at production costs lower than the current prices at which Silica from sand produced in large amounts is sold. This can be used in conjunction with the power generation plants using rice husk.

The state-of-the-art IISc open top reburn downdraft gasification is, thus, a new contribution to modern technology in the field of renewable energy.

Biogas from anaerobic digestion of (a) distillery effluents, (b) urban solid waste processing plants, and wastes from (c) dairies, (d) abattoirs and other industrial waste treatment plants contains largely Methane (55 to 65 %), and Carbon dioxide (30 to 35 %) along with 0.5 to 5 % of Hydrogen sulphide. The gas is usually used for steam raising with the emission of Sulphur dioxide. It cannot be used for power generation via reciprocating engines or gas turbines unless the Hydrogen sulphide is brought to negligible values, certainly not more than 0.15 % in the worst case. A chemical based treatment process has been developed towards “sweetening” the “sour” gas. This has been applied for throughputs of 600 m^3/hr to generate up to 1 MWe. System modifications to deal with much larger contents of Hydrogen Sulfide in industrial plants have also been understood.

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An Overview of biomass gasification system

This chapter summarizes several aspects related to the biomass gasification process based on some of the information available in the literature and the experience at Indian Institute of Science, Bangalore.

Gasification of biomass for use in internal combustion engines for power generation provides an important alternate renewable energy strategy. Solar energy captured by photosynthesis and stored in the biomass makes it a high-energy density system (16 MJ/kg). Gasification of this fuel is taken to mean partial combustion of biomass to produce gas and char at the first stage and subsequent reduction of the product gases, chiefly Carbon dioxide (CO_2) and water (H_2O), by the charcoal into Carbon monoxide (CO) and Hydrogen (H_2). The process also generates methane and other higher hydrocarbons depending on the design and operating conditions of the reactor. The development of the technology to harness this route has taken place in spurts. The most intensive of these was during the Second World War to meet the scarcity of petroleum sources for transportation both in civilian and military sectors. Some of the most insightful studies on wood gasifiers - basic as well as developmental - of this period have been well documented in the English translation of the Swedish work.

The effort on the development of gasification systems at Indian Institute of Science has been taking place since 1982. Initial developmental efforts were based on available designs from the earlier literature. Work on the closed top system began at IISc, based on information available from literature, with emphasis on restructuring in terms of practical use.

The SERI (Solar Energy Research Institute) document has in it a description of several systems and statements indicating the difficulty of building reliable gasification systems at small power level. These relate to the quality of the gas in terms of energy content and the particulate and tar content of the gas. Though the poor energy conversion of solid fuel to the gas was acceptable, the higher particulate and tar caused difficulties in using the gas for engine application. Research and development that was attempted during the early forties was limited; yet, many interesting aspects have been documented in SERI. Most of the reporting in SERI has been on closed top gasification system. Several groups, all over the world, continued the work on the closed top system and have been improving the engineering and the control system involving a large amount of financial support from various agencies with a limited emphasis on the basis research towards the understanding of the process.

Initially, the gasification systems were built with wood chips as fuel. Much later, the work that is attributed to Chinese origin, an open top system, for using the rice hulls in as – received mode was developed and several systems based on these concepts have been built in India and Thailand. Consequently, there have been several problems with this design – high tar level in the gas and unconverted carbon in the ash.

Understanding the reasons for several of the issues called for fundamental studies. These studies as well as design and developmental work with extensive experimentation have resulted in a reactor design at IISc that can be used for any bio residue. This evolution resulted in abandoning nearly all concepts evolved in the closed top system for a user-friendly, modern gasification technology. This design can reassure a user that the gasification process yields high-quality gas with little tar and particulates. *One of the crucial reasons for the successful development of a reliable gasification system to handle any bio-fuel is the fact that the same team dealt with basic research, technology development, and field installation, debugging problems in the field and design improvement.*

Scientific aspects of reactor design

The first element in a gasification system is a reactor where the thermo-chemical conversion from solid fuel to gaseous fuel takes place with reactions taking place with air drawn from the atmosphere in a temperature range of 800 to 1400 ^{o}C. This is the most critical of the components from the point of view of (i) conversion into high-energy gas, (ii) reduction of tar and particulates, and (iii) managing to function under high temperature, oxidative or reducing atmospheres with long life.

Factors involved in the generation of producer gas of acceptable quality

Residence time

The issues of residence time required to generate good quality gas at different throughputs, and the arrangements for the reacting mixture to stay in the high temperature environment in the presence of char for such duration that ensures cracking of higher molecular weight molecules, have not been dealt with in other designs. Often, it is thought that one can convert the solid fuel to gas even at high levels of tar and crack the tar subsequently, in a separate reactor meant for this purpose. While this may be satisfactory at large throughputs (in terms of several tonnes per hour), at low throughputs (~ 1 tonne per hour or less), the system elements will turn out to be prohibitively expensive and difficult to work with. The only reason that one uses such an approach to convert the solid fuels to gas even with high tar is that the reactor dimensions will be contained at large throughputs. (They essentially use circulating fluid beds at fairly high velocity ~ 7 to 10 m/s and hence lower reactor diameter for the same throughput). High temperature in the reactor with reactive char can be made use of to crack tarry gaseous components to low molecular size components that can move with the gas stream without depositing in any low temperature section by providing for adequate residence time.

To summarize the central part of the argument, tar cracking is promoted by two means – uniform distribution of high temperature across the char bed and presence of reactive char. That high temperature is favourable for cracking of complex chemical structures to smaller ones is a well-known phenomenon. Careful measurements by Kaupp (Kaupp's thesis at the University of Davis, 1985) and some tests carried out at CGPL have shown that the tar fraction is reduced substantially if a tar-laden gas passes through a hot bed of charcoal.

Fuel moisture content

Another important aspect is the gasification efficiency defined as the ratio of the total calorific value of the gas generated to the calorific value of the biomass. The gasification efficiency decreases with increase in moisture content of the biomass. If however, wet biomass were to be used as fuel, the calorific value reduces significantly. Also, the tar fraction will increase with increase in moisture in the biomass due to the decrease in average bed temperature. One not-too-well appreciated feature of the effect of moisture content in biomass in gasifiers is that the gasification efficiency drops with increase in moisture content. This leads to a double effect. Firstly, increased moisture content implies that the calorific value of biomass is reduced. Secondly, the gasification process that involves oxidation reduction reactions seems to be affected in a manner as to lower the gasification efficiency (ratio of cal value of the gas to that of biomass). Thus one should dry the biomass using the low-grade heat before performing the gasification process in order to optimise of the total calorific output.

Fuel Size

The fundamental consideration for the choice of the size of the biomass is related to gas quality, material movement, and tar generation. Use of very large-sized biomass creates very little surface area per unit volume of the reactor (in the reaction zone) so that the volatilisation becomes less than adequate and the quality of the gas comes down. Use of too small-sized biomass leads to significant pyrolytic liquid fuel generation (otherwise called for in other applications) even though the gas quality is good in this limit. Hence, one needs to select fuel in a range of sizes that permits good quality of gas composition while still allowing for cracking of tar to a significant extent. The typical rule of thumb is that one should use biomass size about one sixth to one twelfth of the reactor diameter, preferably a mix of sizes than a single size. The use of a range of sizes allows better packing and interception of gases adequate enough for good conversion. Also when the biomass chip size decreases, the pressure drop across the reactor will increase to an extent of posing an upper limit for operations with typical pressure budgets of small systems (about 500 mm water gauge).

In the extreme case of pulverized fuel being used in the same reactor as solid pieces of biomass, one gets poor quality gas and tar in any practically meaningful operating period of time. This occurs because the movement of biomass takes place in an uneven manner leading to specific pathways through which flow occurs. This feature, on occasions, results in tunneled pathways right through the bed to an extent that the gas generated has fair amount of unconsumed oxygen (2 to 4%) and corresponding lower quality of gas and larger amount of tar. If on the other hand, one were to use a cyclone type of gasification for handling the pulverized fuels (experimented at IISc as part of a major project under MNES), one can get good quality of gas, but with a minimum of tar - a borderline of acceptability. This operation in which both air and fuel flow rates are to be independently controlled, results in performance sensitive to the relative flow rates. A shift to slightly less fuel rich condition leads to poorer quality of gas even though tar level is low and a shift to slightly richer condition than the nominal leads to levels of tar higher than acceptable levels. The reason for the presence of a minimum of tar in a cyclone gasification system, somewhat more than what one would get in fixed bed open top downdraft reburn reactor, is that the small particles hitting the wall of a hot cyclone (close to flash pyrolysis) lead to particle heating rates close to optimum liquid fuel generation rates. The liquid components need to be cracked inside the reactor at high temperatures with reasonable residence time. This occurs, but even these processes seem inadequate to reduce the hot-tar fraction to levels of 100 to 150 mg/Nm^3(ppm) that are expected from fixed bed downdraft solid biomass reactors. Typical levels experienced in the cyclone reactors are about 700 ppm of hot tar under steady and controlled conditions of operation. Slightly richer operation leads to tar levels of 1500 to 2000 ppm. These studies have shown that cyclone systems are perhaps inadequate to meet the stringent demands of gas quality for electrical of select high grade thermal applications. These results indicates the choice of the size of biomass to be used in fixed bed downdraft systems.

Agro residues as fuel

The next aspect considered is the demand for a gasifier for non-woody biomass. Non-woody biomass comprising of agricultural residues like rice husk, bagasse, sugarcane trash, groundnut husk, mustard stalk, mulberry stalk, cotton stalk, jute stalk, coconut residues like coconut shells, fronds, and coir pith, industrial wastes like marigold waste, plantation residues like tree droppings, pine needles, sidelings of trees that are left behind on the field, and weeds like ipomia, ipatomia, and prosopis juliflora. Of these biomaterials, coconut shells, and fronds, cotton stalk, mulberry stalk, jute stalk, tree droppings and ipomia have the structure of woody material with low ash content (less than 2%) with reasonable density and could be accepted in the standard gasifier meant for wood chips with some or no modifications. If the particle density is small, as will happen in the case of ipomia or mulberry stalk (~ 200 kg/m^3), the volumetric flow of the bed will be high at the same mass throughput. The start-stop operations of the gasifier are beset with bridging problems leading to material flow difficulties particularly when operated at low throughput. However, on a continuous operation mode, there will be much less problems, when operating at near full load.

For light and fine sized materials like rice husk, sugarcane trash, coir pith, bagasse, groundnut shells, pine needles, the form and size are different. Any approach to use these materials on an as-is-received basis would lead to material movement problems. The solid fuel can be made homogenous by pulverizing them. Having pulverized the material, one simple approach of making the material a solid stock would be to briquette or pelletize it. The solid briquettes are dense and lend themselves to be used in a classical woody biomass gasifier as long as the ash fusion-related issues are taken care of in the design. An additional feature of briquetting is that the classification to values close to 1000 kg/m^3 permits transport at reasonable cost for light agro-residues and leafy plantation residues. Some class of biomass lend themselves for direct use or through briquetting. The light stock like of cotton could be used directly or pulverized and briquetted to enable economic transportation over longer distances.

Rice husk occupies an important part of the bioresidue from paddy milling operations. Asia depends on rice very significantly and hence rice husk is one of the very large wastes in the continent. As noted earlier, the Chinese group developed an open top concept to gasify the as-received rice husk. This technology found its way to Thailand and India and several gasifier manufacturers have produced many local variants keeping the reactor design the same. Its acceptance has resulted from two simple considerations: (a) the system can accept rice husk on an as-received basis and (b) the reactor design is fairly simple – it has a article insulated reactor with bottom region having a rotating grate to extract the residual char/ash. The gas, drawn at the bottom, goes through an elaborate cooling cleaning system. The gas from the reactor could be very tarry and so, an elaborate scrubbing system is required to remove the tar. The material extracted at the bottom is largely unconverted char. This is drawn away through a water seal and washed out. The rice husk consumed at power levels of 100 kWe is about 2 to 2.2 kg/kWh amounting to a very low conversion efficiency of 14%. This is consistent with the fact that virtually no char conversion takes place and the reactor acts like a pyrolyser albeit with some reduction of tar fraction due to the passage of the air/fuel gas mixture through the hot char bed. Its use in India for engine applications has resulted in engine seizure at few industrial locations where continuous operation of the system was intended. No detailed performance test data have been reported. The near no-conversion of char is due to the char conversion process being quenched. It is not immediately obvious why rice husk char quenches after the flaming process (during which the volatiles burn up with air) whereas fine pieces of wood char continue to react with hot gases until very significant conversion takes place.

In order to understand the above behaviour, the extinction phenomenon as a function of particle size and ambient oxidant fraction and temperature was explored experimentally. Typically, a 2 mm wood sphere, after flaming, will get extinguished at atmospheric conditions. Rice husk char with its peculiar structure with wall thickness of 0.2 mm can be expected to experience char extinction because the reactivity of rice husk char with about 40% inert is much lower than wood char about 5% ash; this explains little or no conversion of char in rice husk gasifiers. Further, rice husk briquetted into 25 to 50 mm size can be driven to complete conversion within the reactor with tar levels comparable to or lower than for woody biomass; the lower values relate to less complex tar emanating from rice husk de-volatilization. These are the reasons for the classical Chinese technology to be energy inefficient; the disposal of unconverted char by discharging the material with copious amounts of water is environment unfriendly; replacement by a modern open top reburn system for use with rice husk briquettes ensures better efficiency besides being environment friendly.

Ash fusion is an issue that is bothersome in the operation of the reactor. This problem was not faced in the closed top WW II design more because it was meant for clean wood chips and the discipline in operating the systems was adequate enough not to include inorganic matter that might cause ash fusion-related problems. If one were to use agro-residues, the discipline involved in handling the fuel on the field in several developing countries is such that a pick up of few to several percent of inorganic matter in terms of mud, sand, and grit is not unusual. This r method of fuel handling is not considered inappropriate because, the fuel would not pose any serious problem while being used in the combustion route. Use in gasifiers' leads to ash fusion inside the reactor to an extent that the entire reactor may get clogged. *Hence, one needs to ensure that these problems do not occur.* Several residues like sugarcane tops and leaves that contain a fair amount of potassium have problems of ash fusion caused by the lowering of ash melting point because of alkaline matter. Fundamental considerations show that the temperature attained by the hot char particle in the flowing stream containing some oxygen (air) depends on the local stream speed. If one uses a reactor configuration that allows high local velocities, the local temperature increases to an extent that ash fusion might occur. The ash fusion issues were handled by maintaining low bed velocities (*see* appendix I for the description of a simple apparatus for determining the conditions that lead to as fusion and some results).


GASIFIER

2

Developmental aspects related to system configuration

This chapter addresses the process design of various elements in the gasification system at IISc. The major parameters highlighted in the previous chapter are considered here during the development. The various elements include – reactor, cooling, cleaning systems and necessary auxiliaries. The issues addressed include robustness of design, life and safety.

The Reactor

Developments at IISc began with small systems. There were inputs from literatures indicating the problems of achieving consistent gas quality both in terms of composition as well as tar and particulates. These were considered in the design and development studies. It was first confirmed through experimentation on classical closed top downdraft gasifiers (with throat) at the laboratory that the observations in literature were indeed correct. The performance of the system, on occasions, was excellent with little tar content and on other occasions, for no apparent reason, produced reasonable amount of tar. This behaviour was traced to the structure of the bed with varying fuel chip sizes and moisture content. While a large power level system would have a favourable heat generation to heat loss ratio, it would be difficult to obtain this behaviour in small power systems with unfavourable volume-to-surface ratio.

The major feature of the basic reactor design at IISc relates to the open top, the choice of L/D ratio and the use of air nozzle/s. The reactor was made upon of two concentric shells, with gas passage in the annular space and the fuel from the inner cylinder. The outer shell was insulated to prevent heat loss. The choice of open top and air nozzles provided the necessary conditions for stratification – a feature helping in movement of the reaction front into the fuel. This helped in establishing a temperature profile inside that reactor favouring cracking of tar. The air for combustion inside the reactor comes from two sources (i) an air inlet nozzle/s and (ii) from the open top through the bed of fuel chips. About 30-35 % of the air comes from the air nozzle and the rest from the top. Reed et al (1984) did not explore this alternative of having an air inlet nozzle in the lower zone. Since all the air was drawn from the top through the bed of wood chips, the average combustion temperatures were lower and this could have resulted in poor quality gas at lower rates of gas generation. Induction of air from the top causes what is termed as stratification of the fuel charged. The volatilies are released at some stage in the downward path of wood chips. Mixing with air from the top causes initiation of exothermic reactions and the rise in temperature becomes steep in this zone. The transfer of heat to the upper zone causes an earlier initiation of the release of volatiles. This would mean an isotherm, say at 700K, slowly creeps upwards and the gasifier never attains a steady state during the few hours of its operation in terms of the thermal profile both in the reactor and in the annular space, as long as air is drawn from the top. If the supply of air from the top is cut off, the temperatures inside the gasifier and the annular space would attain a steady state about an hour after the cut off. It is important to note that the gas quality is not affected by the non-attainment of a thermally steady state in the gasifier. It is possible that there is some shift in gas composition, but it does not seem to have any significant effect on the calorific value of the gas. The calorific value remains steady and within about 20 % of the average throughout the operation period. The significant advantage of the features described above is that even the relatively wet wood chips (upto 25 % moisture content) to get dried and charred before reaching the second air entry region. Another benefit from passing the hot gases through the annular space is with regard to how the material movement is facilitated inside the reactor. As mentioned earlier, an isotherm of 700 K is established along the length of the gasifier implying that the wall is very hot. Hence there is no possibility of any considerable (tar) sticking on to the wall and causing bridging, thus assuring reasonably good material movement.

The next version of the reactor was made of vertical tubular reactor with an open top and a water seal at the bottom. The lower two-thirds portion of the reactor, where the reactor bed temperature exceeds 600° C, was lined with a ceramic material of lower thermal conductivity. This zone is from about 0.75~m above the air nozzle to the reactor bottom. This is to prevent high temperature corrosion in the presence of CO_2, O_2, CO, and carbon in the reactor. The upper part of the reactor is made of stainless steel with an annular jacket around it. The hot combustible gases generated are drawn below the grate and taken through an insulated pipe and through the upper annulus of the reactor, where part of the sensible heat if the gas is transferred to the cold wood chips inside the reactor. The entire reactor surface along with the recalculating duct, which connects the bottom of the reactor to the annular region at the top, is insulated with alumino silicate blankets. The hot gas ,which enters the annulus around 500° C, transfers some heat to the wood chips inside, improving the thermal efficiency of the system, in addition to drying the wood chips in this zone. The inner wall temperature reaches > 350°C after a few hours of operation at full power and this condition is favorable for the preparation of wood chips before their entry into the combustion zone.

Choice of material and life

As described earlier, the design had an inbuilt feature of drawing the hot gases out by passing them from the grate at the bottom through the annular region upto the top so that the heat from the gases can be transferred to the incoming biomass. While this design worked remarkably well even with biomass of 30% moisture content, the life of the twin shell stainless syeel reactor (the bottom suction had AISI 310 high temperature steel) was no more than 1200 hours. The failure was mostly at the bottom zone that experiences high temperature and oxidizing as well as reducing environments. This was known after a field experience in which about four hundred 3.7 kW mechanically driven pumping systems were deployed in a major demonstration programme of MNES during 1987 – 1992. Even though the programme served the purpose of the demonstration for over two years (pumping demand is between 500 to 600 hours every year), it showed a major flaw in the design meant for industrial applications where the elements need to work with minimum life of 10,000 hours or more. This led to the consideration of the use of ceramics at least for the high temperature bottom section that experiences both oxidizing and reducing environments. For small systems, it was thought necessary that some heat transfer into the biomass chips inside the reactor would be useful. The design for small reactors was made up of two sections. The bottom section had an outer mild steel shell with the inside having ceramic material and the top section having twin-stainless steel shell structure in the annular space of which the hot gases can flow and transfer heat across the inner shell to the biomass chips.

For the bottom portion of the reactor, several options were tried and rejected before the final configuration was evolved. In the early stages, the configuration involved use of precast ceramic shells inside the mild steel outer shell, with ceramic blanket in between them. It was found that the shell cracked in a short duration and the structural integrity was compromised. Investigations in this regard revealed that the mechanical strength of these shells is better under compression rather than tension. Thus the design switched over from the precast shells to insitu casting with an outer mild steel backing. Further, a configuration with outer mild steel shell the inside of which has standard industrial products, like insulyte and Whyheat-K with outer mild steel shell was adopted. Fig. 2.1 shows the schematic of this version of the reactor. Even though many of the problems mentioned earlier were resolved, one important aspect related to the biomass, i.e., ash fusion posed serious problems by bonding with the lining. This also led to problems of erosion within 1500 to 2000 hrs of operation. Subsequently, the configuration evolved was cold face insulation brick lining followed by hot face insulation brick lining and high alumina tiles on the inner most section. Fig. 2.2 shows the schematic of this version of the reactor. The characteristics of Alumina tiles were found important in that unless the alumina content exceeded 90%, ash fusion and bonding with the wall material problems would prevail. This problem is also, in part, related to the air nozzles provided on the periphery. The life of the top steel shell was augmented by spray coating with aluminium so that any possible high temperature reaction with hydrogen or fine carbon deposits can be avoided. The life of this segment is known to exceed about 2500 hour with subsequent restoration after repair. This strategy of two-part construction is limited to less than 100 kWe (typically, 100 kg/hr system). It was considered essential for 4 to 50 kg/hr, but marginally relevant to 75 to 100-kg/hr class.

At larger power levels, the ratio of heat release rate to heat loss rate is large so that one can dispense with the twin stainless steel shell and go in for a single shell based on ceramic construction. This has been practised for systems with a throughput more than 100 kg/hr.

The other important component related to the reactor is the air nozzle. Depending upon the capacity of the gasifier, the air nozzle diameter varies and so the heat flux around this region. At small power levels (<100 kg/hr capacity) either AISI 310 or ceramic nozzles with about 90 % allumina was found adequate. At large power levels, this concept failed due to high temperature corrosion. Even use of water-jacket with separate water circuit had issues related to salt deposition (from water) in the water jacket. Even with special care on the quality of water the performance was not found satisfactory at field level. This problem has been overcome using a ceramic material to withstand the temperature, mechanical load and corrosion. This configuration was found working satisfactorily over 2000 hours of operation.

As regards the use of agro residues, one important factor that had to be considered was related to the possible high ash content depending upon the material chosen for gasification. The ash composition had a serious bearing on the reactor performance due to ash fusion and slag formation. The increase in pressure drop across the reactor due to the formation of large lumps would result in performance degradation and pose problems for ash extraction. In order to handle this situation initial trails were with rotating grate were made, but did not yield satisfactory results. A distinctly different approach was attempted to handle this situation. A screw based ash extraction system, which supports the entire bed, and assist in the extraction was found to account for usage of various types of biomass briquettes in the same gasifier. The extraction was controlled by varying the duration of screw rotation. Depending upon the end use of the residue extracted, dry or wet methods were used below the screw.

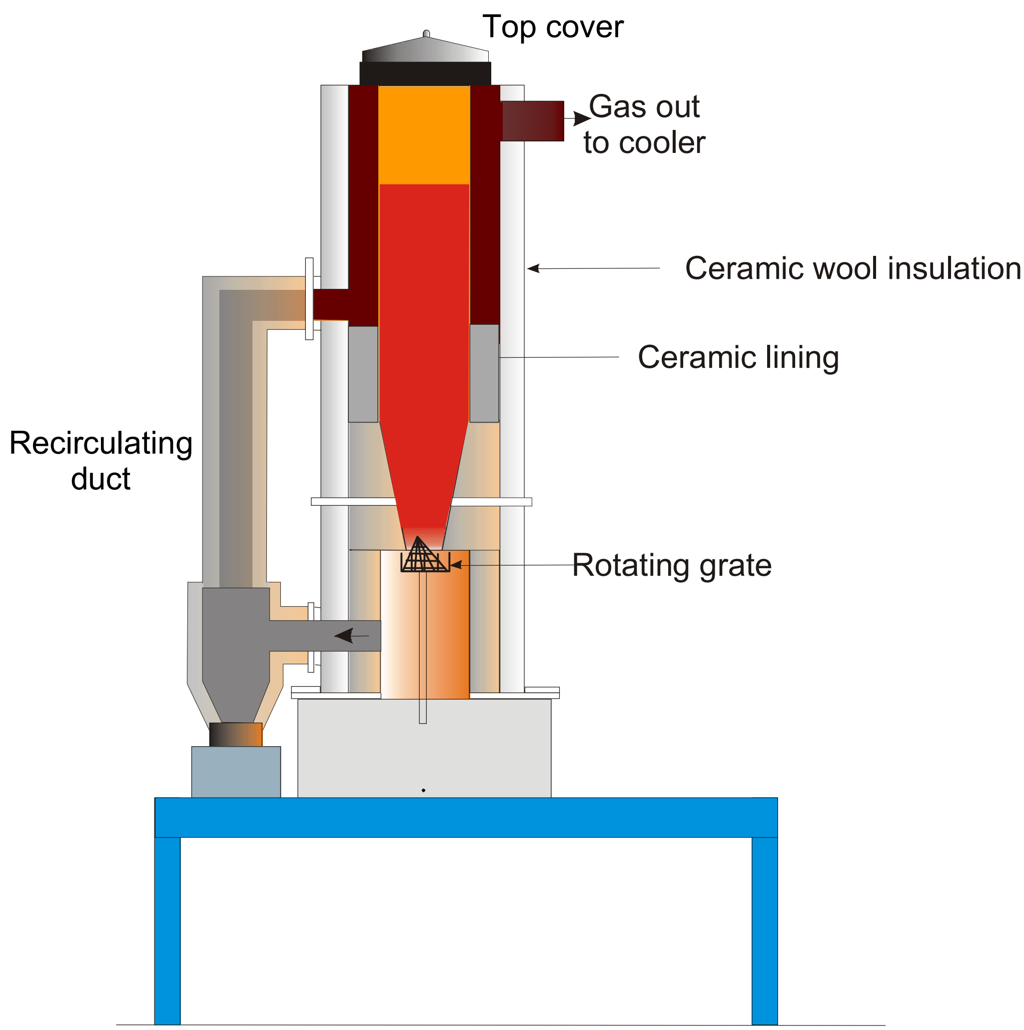

Fig 2.1 Schematic of the reactor with grate

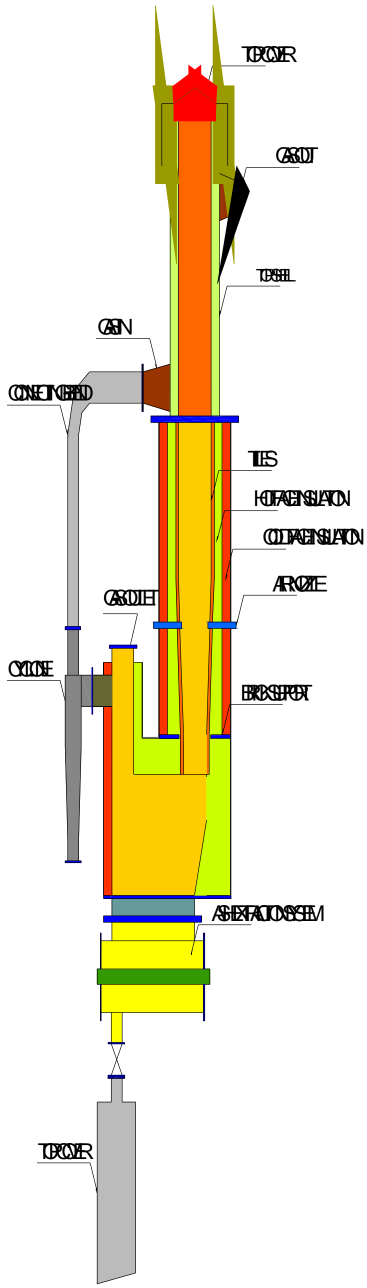

Fig 2.2 Schematic of Reactor with Screw based Ash extraction system

Cooling and cleaning system

For most of the end use devices, gas needs be cooled to nearly ambient temperature and must be much cleaner compared to that for thermal applications. The requirements on the cleanliness are in terms of particulate and tar content. The acceptable upper limit of particulate content appears to be around 50 mg/m^3 (Kaupp, 1984; Stassen, 1993) irrespective of particle size, which is generally less than 10 mm. However, if the particle size is smaller than a few microns, this limit is unimportant as the particulate matter flows along with the gas without deposition during its way to the engine at bends, corners and passages. As regards tar, there has been no clear statement of what the limit is. Understandably, no deposition of tarry material should occur in the passages. Such an occurrence is possible if tar has components with condensation temperature somewhat above the ambient. Most updraft gasifiers produce `smelly' tar, implying presence of components of a wide range of molecular weights including the relatively large molecular weight and this material would condense at near ambient temperatures and also viscous. Downdraft closed top gasifiers with air entry through nozzles also permit leakage paths for relatively uncooked volatile in azimuthal zones between nozzles and this leads to the generation of tar of a kind which still has some low molecular weight components. Open top downdraft gasifiers allow for a more homogeneous bed of high temperature and produce much smaller amount of tar. While the upper limit of allowable tar may be stated at 50 mg/m^3, the real test would be to couple the gasifier to the engine, run it for a specific duration and analyze the deposits in the pipe line, both for particulates and tar. This will establish the time-between-maintenance of various components. While characterization of the gasifier alone has been completed at many places in the world (Stassen, 1993), characterization of the gasifier-engine system has been done in a limited way. What seems clear from the characterization of the gasifier alone and operation on engines is that the engines can run in dual-fuel mode for roughly as long a time before any major maintenance as in diesel alone mode.

In order to increase the density of the gas, the gas is cooled to ambient temperature by indirect and/or direct means and filtered adequately to reduce the particulate content. Cooling in high power systems is best handled by direct injection of cooling water unless there is specific plan of utilization of the low-grade heat. Direct water injection into the gas stream was used for cooling the gas. With respect to filtering a variety of techniques were considered and some tested for a reasonable period of time. Some of these are, use of polyurethane foam, synthetic cloth, coconut coir mat in combination with others and sand bed with specific sand particle size distribution. After these studies, sand bed filtering technique was finally accepted as it is convenient, inexpensive, provides good filtration, and is reusable since simple washing with detergent solution is adequate to refurbish the 1 to 2 mm size particles and the fine sand bed filled with 0.25 to 0.65 mm size sand. The size of the filter area is so chosen that the gas velocities through the filter bed do not exceed 0.1~m/s. This low velocity coupled with the tortuous path causes the removal a large part of the dust from the gas. Experiments have shown that some part of the tar also gets deposited in the filter circuit, particularly when the moisture carry over from the cooler causes slight wetting of the sand bed. Figure 2.3 and 2.4 shows the efficiency of various filters used in many of the gasification systems with an indication of collection efficiency.

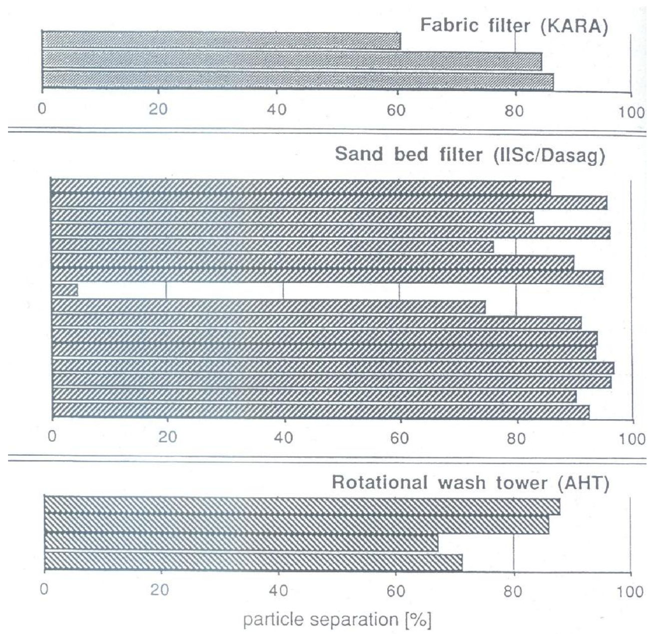

Fig 2.3 Particle separation from a biomass derived producer gas in a fabric, sand bed and a rotational wash tower (Hassler et. al.)

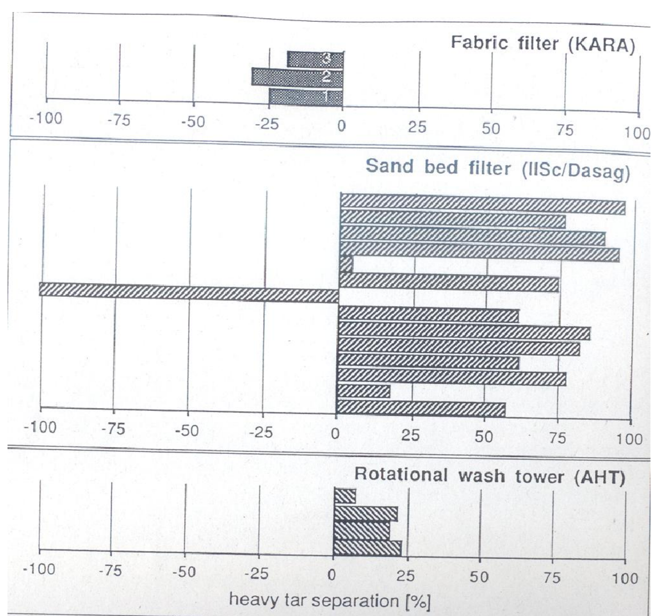

Fig 2.4 Heavy Tar separation from a biomass derived producer gas in a fabric, sand bed and a rotational wash tower (Hassler et. al.)

Even though the performance of the sand bed filtering system was acceptable to meet the requirements of naturally aspirated engines, without affecting the engine performance, the configuration was insufficient to handle a turbo charged engine. The turbo-chargers usually operating at tens of thousand rpm act as centrifugal separators and collect the particles present in the gas. Separation of the dust at the compressor was found to affect the performance by blocking the passages. Further, the downstream element of a turbo-charger meant for cooling the gas - the after cooler, also gets clogged. The result of such an event was found to affect the total airflow and hence the output of the engine, higher exhaust temperature and very frequent maintenance of the turbo. Thus, the gas quality standards established for naturally aspirated engine were found insufficient to meet the requirements of a turbo charged based engine.

Based on the field experience on the use of producer gas at higher capacities and the quality of gas to meet the turbo charge requirements, the cooling and cleaning of the gas was revisited. The problems associated with water circuit for cooling the gas had to be addressed in view of recirculation, to conserve the water usage.

The new philosophy used in configuring the cleaning systems was one of eliminating the dust/particulate in dry form, without significantly contaminating the cooling water. This further reduced the water treatment load.

The contaminations in the gas are the particulates and condensable (tar). Based on the detailed testing on a 100 kg/hr system, it was found that typical particulates and tar were in the range of 1000 ppm and 100 ppm respectively. The initial part of the cleaning system was done by using a high-efficiency cyclone to drop off as much of dust as possible. This also reduces the temperature of the gas. It was possible to reduce the temperature significantly by cooling the outer wall with water. This was, however, considered detrimental since tiny tar deposits, on occasions, could cause build up of hard encrusted material that will lead to blockage later. A simpler approach would be to keep the wall relatively hot, certainly not below 150 °C or so, to prevent eventualities of the kind described here. The provision of an outer metal cover helps buoyant circulation of air. It would also be possible to draw this air and use it for drying the biomass. The first segment of the cleaning system is the same at all power levels. The gas enters a direct cooler-scrubber. Water at ambient temperature is sprayed as impinging jets at impinging angles of 30 – 35^{o}. The jets break up into relatively large droplets and entrain the gas around in the passage downward. The gases cool down and also shed some fine dust in the process. This process brings down the particulate content to about 100 to 150 ppm.

From this point onwards, the design for the pathway of the gas has changed over times. Having cooled the gas, choice of sand bed or other devices were open to the designers. Based on the requirements of better gas quality for turbo-charged engines and the requirements long duration operation in an industrial sector, other devices left behind the sand bed filters. Two approaches were considered to eliminate the fine particulate matter and some tar - the use of diesel venturi-scrubber and another, the use of chilled water venturi-scrubber. Both these were experimented with and indicated tremendous promise. The only defect of diesel scrubber is that in gas engine-based power generation systems, diesel used for scrubbing would degrade over a typical thousand-hour period and had to be disposed of for effective use (about 200 litres for a 500 kg/hr power generation system). The issue with the adoption of chilled water system is that power would be required (about 6 kWe for a 500 kWe class system) in operating the system. But the *remarkable* feature of using the chilled water system in the gas pathway is that the gas is ultra-clean with particulate and tar levels below observable limits. A specific study on the particulate matter trapped in the chilled water system revealed that the particulate matter had a range between 1 to 10 microns with the mean at 5 micron. The chilling operation was favoured for another reason – the gas would reach the ambient temperature and become dry, which in turn, would enable the gas flow path to be dry. The gas would finally pass through a 5-micron fabric filter before being provided to the engine. The final cooling cleaning system configuration was Cyclone – direct ambient water cooler/scrubber – chiller water scrubber – fabric filter. It was also possible that the diesel scrubber would be included. The system is called C^n clean up system (n = 3 to 5 depending on the choice for a given situation)

Essential Auxiliaries

Some of the essential elements, which may not directly involve in the generation of gas, but essential as far the power plant is concerned are, the water treatment plant, biomass preparation, driers and fuel handling systems. The following paragraphs bring out some of these

Water Treatment system for re-circulation

Water being used as a cooling medium also facilitates removal of contaminants like particulates and condensable. If the water is being used in a single pass, the discharge water could meet the pollution standards. Due to high volume requirement of water, it is desirable to have a closed loop water circuit – to be used as re-circulation. Based on the results of Indo-Swiss tests, Table 2.1 provides data on the contamination of water used for scrubbing the gas.

Table 2.1 Effluents per kg moisture free wood for small power level system

Item	P & T	COD	Phenol	DOC	NH_3/NH_4^+
g/kg mf wood	1.45	1.9	0.077	2.32	1.72

m.f = moisture free

Water with the above concentration of contamination cannot be re-used or discharged unless a treatment scheme is incorporated in the system. Treatment of the above water calls for removing the particulate matter, which involves some carbon and ash; and the organic components involving higher molecular weight compounds. Further, water has to be cooled before being re-circulated, to remove the heat gained during cooling of the gas.

The results of the effluents in terms of g/kg of moisture free wood are shown below for the Indo-Swiss test both on a 75kg/hr system (1994) and on the 200kg/hr system. In the recent test, analyses of sulphides and cyanides have also been made. It is reassuring to note that the data obtained in 1994 and the recent data on a larger power system shown in table 2.2 have similar magnitudes. Hence, these data can be considered reliable for design of the effluent treatment plants.

Table 2.2 Effluents per kg moisture free wood for larger power level system

Item	Dissolved Phosphate (PO_4)	COD	NH_3	Phenol	Sulphide (S)	Cyanide (CN)
g/kg mf wood	0.07	2.04	2.87	0.044	0.058	0.009

The detailed assessment of the chemicals in the effluent is presented in the Table 2.3 below. One interesting result that was obtained during the tests that were conducted in a preliminary way has been that the analysis of COD before and after filtering showed that in all cases excepting one (12.07.94 – see later for details of the tests), the change in COD is drastically reduced after filtration. This implies that the COD is arising out of particulate matter. This also provides a simple technique of reducing COD in actual practice through filtration. The general standards for effluent discharge are provided below along with the measured values for the experiment conducted recently at the laboratory.

Table 2.3 Standards for effluent discharge as per Karnataka State Pollution Control Board / Central Pollution Control Board and measured values

No	Substance / characteristics	Spec. mg/l (max)	Amount in the effluent before treatment (mg/l)	Amount after treatment (mg/l)
1.	Total dissolved solids (TDS)	2100	729±3	798±8*
2.	BOD – 3 days at 27^0 C	30	51±1	17±1
3.	Free ammonia	5	229±2	109±2
4.	Sulphides as S	2.0	4.56±0.14	0.82±0.04
5.	Cyanides as CN	0.2	0.68±0.02	NIL
6.	Dissolved Phosphates (PO_4)	5.0	5.6±0.05	1.81±0.03
7.	Phenols as C_6H_5OH	1.0	3.41±0.09	0.40±0.02

* Note that the TDS has increased after treatment because of the addition of the coagulants. The sample after treatment meets the pollution control norms.

Primary treatment

Primary treatment involves removal of suspended solids. This may be done by either flocculation or by coagulation. Flocculation is the mechanical process of bringing the suspended particles together so that they agglomerate. Coagulation is the chemical process, which involves addition of chemicals that alter the characteristics of suspended particles so that agglomeration takes place. These coagulants cause the solids to agglomerate by reducing the 'zeta potential to zero'. In other words, colloids are brought to their 'isoelectric point' so that their 'Brownian movement' ceases. Two coagulants termed A and B engineered from an existing chemical stream for water treatment was chosen after a number of trials. Settling of the solids was found to be complete in 10 minutes time. But, the amount of coagulant used was thought to be high. Coagulant B was noticed in the form of small lumps while agitation was carried out. These lumps sometimes settled at the bottom and sometimes stuck to the sidewalls of the container. Hence, it was concluded that inefficient dispersion resulted in the high consumption of coagulants. By adding the slurry of the coagulants, we had improved their dispersion, thereby allowing the effective usage of the coagulants. Besides improving their dispersion, it is necessary to optimise the coagulant dosage for the effluent by some standard method.

Secondary Treatment

Though the effluent subjected to primary treatment was free from suspended and non-settling solids, it had phenolic odour and brownish colour. To remove these, it had to be subjected to secondary treatment. One of the effective means for removing colour and odour is treatment with activated carbon. Water coming out of the bed was free from colour and phenolic odour, but it had ammonical smell, which was eliminated with the addition of 0.1% (v) concentrated HCl. When checked for pH using the pH meter it showed an acceptable value of 7.1.

Biomass preparation

Over the last 15 years several concepts for fuel preparations were tried. With respect to the sizing of woody biomass stalks to meet the requirements of a gasifier, circular saw has been extensively used due to the non-availability of small chippers. Based on the experience in the field, semi automatic sizing equipment was developed for woody stalks. The device had all the safety features built and also automatic feeding the saw for appropriate sizing. The cutter has been functioning efficiently at several industrial plants for generation fuel for gasifier.

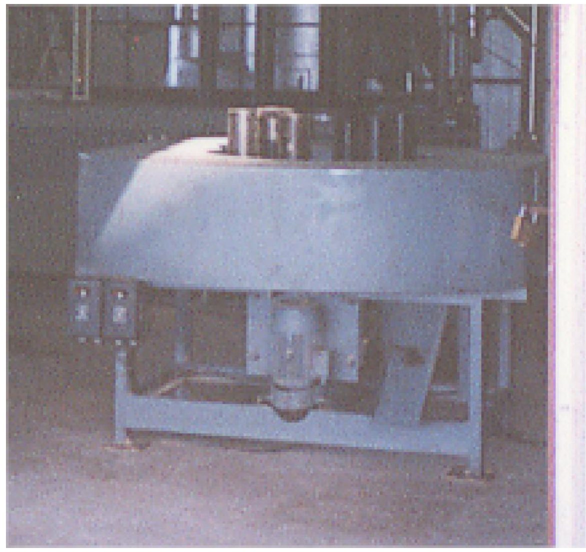

Plate 2.5 Semi Automatic biomass sizing equipment

Further, many of the agro processing equipments have been adopted depending upon the biomass. Even though these have provided some relief to handle specific biomass, biomass sizing has been an area that needs further emphasis to handle the diversified nature of the biomass fuel available.

As far as loose agro residues are concerned, briquetting or pelletising was used to convert into fuel for gasification. The standard techniques available for compaction are, using a ramming press or a screw press – each has advantage for a particular type of biomass. Each of these has limitations on the life of the some of the components. The screw and the ramming type of machines are having a life of about 10 hrs and 200 hours before the maintenance.

Driers

Driers are essential element in the gasification package. The fuel moisture content has a serious impact on the quality of gas generated. Further, the gas quality in terms of tar gets seriously affected due low peak bed temperatures. In order to maintain a controlled fuel quality a drier using the engine exhaust would be ideal or using sensible heat from the hot gas from gasifier or a combination depending upon the situation. The engine exhaust diluted using a blower in the circuit is used to maintain the inlet temperature, less than 100° C. This was passed over a fuel bed to dry the biomass in a separate enclosure/chamber.

Plate 2.6 Drier using engine exhaust heat

Fuel handling systems

Biomass being available in various forms poses problems in preparation and conveying. A standard bucket used for handling most of the solids has been found unsuitable as a universal solution. For example, a bucket elevator designed for coconut shells was found to create problems to convey woody biomass. Based on several studies it was found that a hoist had the greatest facility in handling different biomass of various sizes and shapes.

Safety Aspects

It is true that the gas that is produced is poisonous. Its fire hazard is about the same as other gaseous fuels but the health hazard is quite high. One of the safety aspects with regard to gaseous fuel, LPG, is the introduction of a bad odour producing chemical namely mercaptan (SH related compound) into the gas, which otherwise, has neither colour nor smell so that one can get foul smell when there is leak. In the case of producer gas, there is some smell arising out of tiny fractions of higher hydrocarbons (in ppb levels) and will form a comparable feature for safety if there is a leak.

The design emphasises the use of standard flanged joints with gasket/ O-rings of right quality for various operating conditions, i.e, high and low temperature joints. Depending upon the applications, the last segment of the cold gas plumbing could be either under positive or negative pressure. Thus in major part of the gas path, pressure is below ambient and air can enter the system, while the gas path from the exit of the blower would be at higher pressure, allowing for gas leakage to the ambient.

The gas leakage into the ambient is easily detected using standard water bubble tests, but any air leaking into the gasifer is not easily detected. In order to facilitate detecting any air leak into the system, an oxygen monitor is used on the gas line.

Currently, there are more than fifteen systems (of this design) working in different environments – (a) two village electrification systems for twelve and eight years respectively having operated the gasifier-engine combination for 22,000 hours totally, (b) a private farming location for two years having operated the gasifier – diesel engine and gasifier – gas engine combinations for more than 3100 hours, (c) an industrial unit at Orchha for more than three years and 15,000 hours of cumulative operation, (d) four major industrial operations on marigold drying and heat treatment furnaces have clocked 13,000, 4100, 4500 and 10,000 hours and in each one of these cases, the system has run for 600 to 650 hours a month, some times for 72 hours continuously, (e) one system in an island in Chile for more than 2500 hours and (f) Six systems in rural environment. The operators running the system come from a wide variety of upbringing — some educated, some, little education but very skilled and several unskilled. The only complaints that have been heard from one location is one a headache where the operators who had been atop the gasifier for more than a shift nearly all the time on the top. This is clearly the sign of ingestion of carbon monoxide at ppm levels continuously. The suggestions made for establishing the plant are that the reactor hardware and the gas supply section to the engine/furnace must be in places that are well ventilated and that operators must be moving about generally also observing the system unless the system is of such a large power level that one can install instrumentation and visual monitoring systems.

Regarding the fire hazard and associated thermal explosion possibility, the issue is related to a mixture of gas and air in flammable proportions getting ignited in a burner at unwanted times. There have been four cases of such a nature leading to thermal explosion with effects such as bulging of the outer cover of a filter, lifting of the top cover of the gasifier, and blowing off of a safety diaphragm near the engine. It is useful to explain the circumstances of the explosions. First point to note is that the gasification system has two/three water seals. These provide protection against the entry of air from the atmosphere into the gas line. The explosion problem arises when the pressure drops across the elements are so large that air ingestion occurs through the filter water seals. This leads to a gas-air mixture flowing into the engine or the burner. In so far as the engine is concerned, the fact that gas-air mixture flows implies that the diesel replacement may be lowered, but nothing else. If it flows into the burner after a changeover from engine mode to burner mode and the gas gets lit, there is a possibility of flame travel back into the ducting, particularly when the flow rates are being reduced (like when blower is turned off). This leads to the flame reaching all the way into the large volume filter where the spontaneous combustion leads to large pressure rise and explosion. Thus, the key to the problem is the presence of an oxygen monitor in the pipe taking the gas to the burner or the engine. The recommendation is that if the oxygen fraction is larger than 2.5%, the gas should not be ignited. When this recommendation has been followed, there has been no other problem reported from the field installations.

The other problem that arises is the backward flame propagation from the engine intake valve. This can happen if the dirty gas deposits some unwanted material on the valves and the valve does not seal the intake region. The leaking intake/exit valve could allow the flame in the cylinder to propagate into the intake manifold. This can lead to the propagation of a flame into the intake manifold and therefore there is need for a burst diaphragm in the intake manifold area. Such problems have not been observed in any field installations since the gas has been ultra-clean and depositions in the intake manifold region have not been found.

System reliability

Industrial clients have raised questions concerning the operational reliability and the long duration over which the system is run. Earlier experiments were conducted on smaller systems that were required to work for 5 to 8 hours a day. These were built keeping in mind the fact that continuous operation is not demanded of them. The start-stop operations have some negative points – the system will grow cold over the day and the restart operation takes a fair amount of time for system stabilisation each day. The reactor elements go through a thermal cycle that is quite harsh compared to continuous operation. The key feature in the design of continuous systems is the ash extraction system that should operate roughly in a mode similar to biological systems in so far as input-output relations are concerned.

Loading wet biomass invariably produces poor quality gas, tar and biomass bridging problems. Use of dry biomass is sometimes ignored leading to very messy clean-up actions before the system can be restored to normal operation. Loading unclean biomass leads to ash fusion problems as noticed in some installations. Many of these occur because of the unwillingness of the operators to realise the seriousness of the problems that may result from what they see as a small deviation. This has been noticed even after providing a gasifier operation and maintenance manual in which these issues have been clearly brought out.

The dry dust removal systems via cyclone are usually designed for periodic operation for the ash to be taken away and do not provide any difficulty if the ash collected in the cyclone is drawn away appropriately. Otherwise pressure drop across the cyclone becomes a serious matter needing immediate attention.

The cleaning system with direct water spray can provide problems if the dust/particulate matter gets collected in a manner that water flow rate is affected. This problem has been noticed in many field situations. Either periodic check on the injectors has not been made or during some period, dirty water has been allowed into the cooling system.

Systems that used sand bed filters have had the problem of water inflow into the bed due to excessive pressure drop in the circuit, many times due to difficulties in the reactor operation, some times with unclean biomass. These difficulties have coupled effects that need breakdown maintenance that is time consuming.

In a recent commercial operation at Bulle, Switzerland, the 100 kg/hr system running a 65 kWe gas engine ran continuously without operator intervention except when loading biomass periodically (once in eight hours) into a bin for a duration of 30 hours at one time and 50 hours at another time. The control system with advanced web-enabled features was arranged in a manner that should there be a fault, the system would send a signal to the manager via internet telecommunication to his mobile and shut down the system. This clearly shows that system can indeed be very reliable.

3

Performance tests under laboratory conditions

Laboratory studies have been detailed over a period of eight years. The test results for clean biomass like wood chips as well as briquetted biomass are described here.

Gasifier tests in India

Gasifier tests with standard wood and mix of fines and standard wood.

The gasification system built in India was tested at CGPL in mid-January 1994. Several preparatory tests were carried out in December 1993.

These results are the outcome of collaborative testing between Indian Institute of Science, Bangalore, and Dasag, Switzerland as well as ETH, Switzerland. The gasifier system developed at Indian Institute of Science was tested to determine the gas quality and consistency in its operation for a possible deployment of this technology on gasifiers in European countries. The gasifier system consisted of an open top reactor reactor, a cooling and a filtering system along with a blower and a burner. The details of the configuration of the system are described in Mukunda et al(1994). The test conducted were in the thermal mode, i.e., after cooling and cleaning the gas, the gases were flared. The main objectives of the tests were to determine the gas composition, and tar and particulate levels at the hot and cold ends at various loads. The gasifier was tested with wood chips (casuarinas) of 50-70 mm long and about 25 mm in lateral size and in particular test with mixture of 50% of the above size along with small twigs of 1-10 mm diameter and 25-75 mm long with 5% saw dust. The moisture content was in the range of 10-12%.

Instrumentation and measurement scheme

The system was instrumented to obtain data on the surface temperature of the reactor, gas temperature, and static pressure at various locations, along with gas flow rate using a venturimeter. All the data were logged onto a computer using suitable transducers. The gas composition was measured at the exit of the filter using a gas chromatograph and an online measuring system for CO_2 and O_2 using NDIR and electrochemical method respectively. The measurements were aimed at obtaining mass and energy balance during the various tests along with the amount of chemical pollutants in the cooling water and the various water seals. The tar and particulate in the gas was measured both at the hot and cold end of the gasifier. The first measurement would give the performance of the reactor i.e. how much tar is generated whereas the cold end measurement would give the quality of gas that the engine would be running on.

The apparatus for measuring tar and particulates was built based on the procedure identified by the Swiss group and the final set up was evolved by subsequent experimentation. Figure 1 shows the details of the apparatus. The apparatus was designed to run for 6 - 10 hours. It consist of a series of wash bottles - two of 3 liters and five of 2 liters capacity. The gas was bubbled first through the 3 liters bottle filled to one-third capacity (1 liter) with water to remove dust and moisture and taken to another empty bottle to trap any droplets which arw carried over. These two bottles were kept in an ice bath. The gas from the empty bottle was allowed to bubble through three bottles one-third filled with anisole (200 ml; used as the solvent for dissolving tar), and through an empty bottle to collect any carried over anisole droplets. At the exit of the empty bottle, thimble filters amounting to an area of 500 cm^2 is provided in another three liter bottle, to trap any particulate matter escaping the wash bottles. The gas was drawn through the system by a vaccum pump, and was passed through a venturimeter for monitoring the flow rate and a flow integrator to obtain the total gas sampled before being led to a swirl burner. Extensive precautions (both pressure and vaccum test) were taken to ensure the sampling system is leak proof, as this would be very critical to the accuracy of the measurements on the level of tar and particulates. Any leakage in the apparatus could be detected by examining the flame in the burners as the leakage of the air into the sampling system would transfer the diffusion flame in the burner to premixed mode.

The tests

The tests were planned at three loads namely, 33 %, 55 % and 100 % of the rated capacity and for duration of 8 -10 hours. The gasifier is ignited at the air nozzles; the gas produced is flared in a burner. During this period the temperature, pressure and mass flow rate of gas were recorded on a computer. Flow rate was gradually increased to the desired value. It was ensured that the temperature profile in the reactor has become nearly steady before initiating the tar sampling. The tar and particulate sampling bottles were leak tested before being introduced into the sampling train. Gas at a nominal flow 2 m^3 per hour was isokinetically drawn at the cold and the hot end through the sampling train to the burner, where it was burnt. At the end of 4-5 hours of sampling (approximately 8 - 10 m^3 of gas), the tests were stopped. The samples were taken to an external agency (Cosmic Industrial Laboratories, Bangalore, India) for further analysis, as per the procedure identified by the Swiss team. The tar content was obtained by evaporating the solvent after filtering out the particulates and soxhlet extraction of the particulates and the thimble filter and weighing the residue quantity. Table 3.1 shows the results of the different tests carried out during this period. It is clear from the table that the average particulate content at the hot end is about 600 ± 100 mg/m^3 and 70 ±15 mg/m^3 at the cold end. The tar levels are at 70 ± 30 mg/ m^3 and 20 ± 10 mg/m^3 at the hot and cold end. The results of 12-1-94 and 19-1-94 are in some error due to the measurement and sample collection

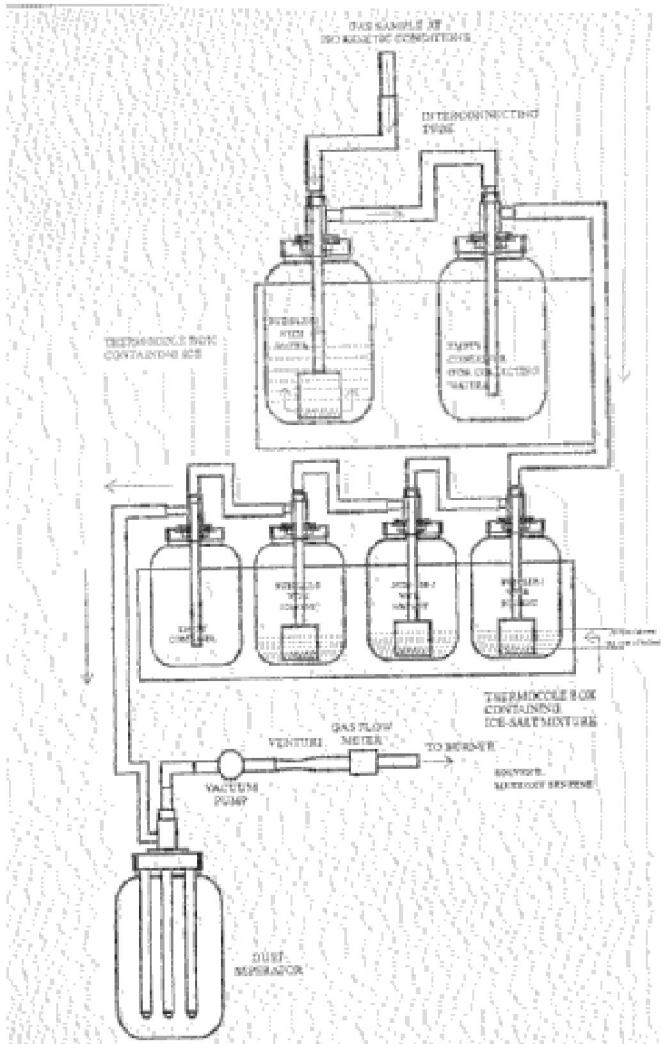

Fig 3.1 Schematic of Tar sampling unit

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Table 3.1 Particulates and Tar in mg/m^3

Date	Load%	Particulate and tar mg/m^3		Particulate mg/m^3		Tar mg/m^3	
		Hot end	Cold end	Hot end	Cold end	Hot end	Cold end
28.13.93	39	751	-	706	-	45	-
1.1.94	111	-	66	-	54	-	12
6.1.94	98	717	-	676	-	41	-
12.1.94	33	729	185	584	66	145	119
14.1.94	55	663	102	562	87	101	15
16.1.94	55	899	78	774	47	125	31
19.1.94	100	796	191	722	45	74	146
11.2.94	33	562	63	501	52	61	11
17.2.94	100	686	76	642	66	44	10

These data are at lab conditions; to get results for standard conditions multiply mg/m^3 by 1.19

The gas composition was measured using gas chromatograph at the old end after the filter. The continuous on line oxygen monitor recorded value of less than 0.1% throughout the run, indicating that there was no leakage of air into the system beyond the reactor. The CO_2 monitor recorded an average 12 + 2 % during the run. The average gas compositions during the tests are given in Table 3.2.

Table 3.2. Average gas composition and calorific value (LCV)

Date	CO	H_2	CH_4	Comb	CO_2	N_2	H_2O	Total	Q MJ/Kg
12-01-94	17 ± 0.5	20 ± 0.5	1.5 ±0.1	0.25	14.5 ± 0.5	48 ±0.5	3.0	104.2	4.34
14-01-94	17.2± 0.5	18.3 ± 0.5	1.2 ± 0.2	0.25	12 ± 0.3	46 ± 0.5	3.0	97.95	4.38
16-01-94	19 ± 1.5	18 ± 0.1	1.4 ± 0.2	0.25	12.6 ± 0.2	47 ± 0.5	3.0	98.25	4.43
19-01-94	19.5 ± 1.0	18.5 ± 0.2	1.4 ± 0.2	0.25	12.5 ± 1	48 ± 0.5	3.0	102.5	4.48
11-02-94	15 ± 0.2	18.7 ± 0.2	1.25 ± 0.1	0.25	13.3 ± 0.3	46.7 ± 0.2	3.0	98.0	4.23
17-02-94	17 ± 2.0	18.5 ± 0.2	1.1 ± 0.1	0.25	12 ± 0.5	46.5 ± 0.5	3.0	98.3	4.48

The mass and energy balance

The carbon balance data for the four tests are presented in table 3.3. As can be noticed the error in the carbon balance is small and hence the mass balance is well satisfied. The energy balance is carried out using data available on the fuel input (wood chips) into the reactor, gas calorific value using gas composition and the heat loss at various locations in the gasifier system (based on temperature measurements). At full load, the cold gas efficiency is about 79 %. The other values relating to the losses are indicated in table 3.4.

Table 3.3 Balance of C

	Date	SI	YI	YO	SO	diff. %
Balance of C	12-01-94	.425	.157	.435	.151	3.93
	14-01-94	.425	.156	.431	.149	4.64
	16-01-94	.425	.155	.453	.155	.21
	19-01-94	.425	.159	.436	.153	3.59
	11-02-94	.425	.156	.437	.148	3.46
Balance of H	12-01-94	.067	.023	.067	.023	.53
	14-01-94	.067	.023	.068	.023	2.10
	16-01-94	.067	.023	.066	.023	.70
	19-01-94	.067	.023	.067	.023	.44
	11-02-94	.067	.023	.067	.023	1.03
Balance of N	12-01-94	1.44	.502	1.46	.507	.85
	14-01-94	1.46	.504	1.49	.515	2.06
	16-01-94	1.48	.506	1.47	.502	.68
	19-01-94	1.42	.499	1.43	.502	.57
	11-02-94	1.49	.508	1.51	.514	1.12
Balance of O	12-01-94	.912	.317	.916	.319	.38
	14-01-94	.919	.316	.905	.312	1.45
	16-01-94	.922	.316	.927	.317	.48
	19-01-94	.905	.318	.905	.318	.02
	11-02-94	.927	.315	.924	.314	.37

SI = Mass of the element /in the input unit mass of wood; YI = Mass fraction of the element in the input
SO = Mass of the element/in the output unit mass of wood ; YO = Mass fraction of the element in the output

Table 3.4: The detailed energy balance of the system in various tests

Energy Form	**12/1/94; 18g/s 33% load (kW)**	**14/1/94; 30g/s 55% load (kW)**	**16/1/94; 30g/s 55% wm load (kW)**	**19/1/94; 54g/s 100% load (kW)**
Energy into wood, kW	+ 110	+ 175.9	+ 173.7	+ 319.2
Energy lost in recirculating duct, kW	- 0.654	- 0.76	- 0.76	- 0.88
Energy from twin shell to ambient, kW	- 0.4	- 0.50	- 0.52	- 0.68
Sensible heat + latent heat, kW	- 6.49 - 6.25	- 14.2 - 10.74	- 13.8 - 9.5	- 26 - 15
Energy from reactor walls into ambient, kW	- 1.82	- 2.04	- 2.04	- 2.14
Energy in char, left in the reactor & cyclone water seals, kW	- 0.43	- 1.43	- 3.00	- 7.40
Energy in tar & dust, kW	- 0.29	- 0.293	- 0.56	- 0.76
Energy in reactor walls, kW	- 0.80	-	-	-
Energy in gas, kW	- 85.1	- 139.3	- 139.5	- 250.2
Total -ve, kW	-102.2	- 169.2	- 169.8	-303.1
(+ve) + (-ve), kW	+ 7.76 (7%)	+ 6.7 (3.8%)	+ 4 (2.3%)	+ 16.14 (5%)
Cold gas efficiency, %	77.3%	79.2%	80.3%	+78.4%

The effluents

The overall effluents generated per kg of moisture free wood are listed in Table 3.5.

Table 3.5: Effluents per kg moisture free wood

Item	P+T	BOD	COD	Phenol	DOC	NH_3/NH_4
g/kg mf wood	1.45	0.14	1.9	0.077	2.32	1.72

The Cosmic Industrial Laboratories carried out the analysis on the cooling water and the water below the seals. These results are consistent with that analyzed by the Swiss team (samples carried from Bangalore). The levels of BOD and COD are in the range which could be treated easily before discharging into the drain. The particulate matter consisting of fine carbon and ash could be removed by filtration. The low level of BOD is argued to be due to the effective thermo chemical processing of the gas in the reactor. The contribution of COD is from particulate matter sine the COD on ultra fine filtration 2 micron filter, is much lower than before filtration. Thus the removal of particulate matter would reduce the COD. The other elements would call for specific treatment.

Gasifier test and briquettes

Second series of tests were conducted in early 1998 to demonstrate the capability of open top down draft gasifer to handle briquettes of varying ash content. Energy grass and restholtz (loose briquettes of powdered wasted from Swiss furniture industry) were shipped to the laboratory for testing along with briquettes of locally available rice husk and saw dust. The energy grass was thin long fibres close to hay. This was chaff cut pulverised and then taken for briquetting. Both screw extrusion and punch and die type machines could not produce briquette. In order to get good briquettes, it was decided to add material so that the mixture can be briquetted. Hence, saw dust was added in 50% and 70% mixture to get two class of 50-50% (saw dust – energy grass) and 70 -30% (saw dust – energy grass) briquettes from punch and die type briquetting machine. The restholtz was 100 mm loose briquettes with an average density of 350 kg/m^3. The as received properties of these fuels are shown in Table 3.6. Table 3.7 shows the gross properties of fuels used for testing.

Table 3.6: Gross properties of as received fuels from Switzerland

Feed stock	Density, kg/m^3	Ash content, %
Grass	50 – 55	8
Restholtz	350	2.5

Table 3.7: Gross properties of fuels used for testing

Feed stock	Density, kg/m^3	% Ash content (moisture free basis)	% Moisture (wet basis)
Restholtz	350	2.5	11.6
Saw dust	1000	17.25*	9.6
Rice husk	850	22	7.6
Grass 50% + Saw dust 50%	550	8.2	12.4
Grass 30% + Saw dust	720	7.5	9.2

* High ash content is due to sand and grit inclusion

The test procedures remained similar as in case (a) and all the fuels were gasified without any problems in the test duration. Table 3.8 to 3.11 summarizes the results of the tests.

Table 3.8 Hours of run and purpose

Test date	Feed stock	Run time	Objective
19/02/98	Restholz	5 hrs 45 mins	Testing of Restholz briquettes at 33% load
28/10/99	Grass and saw dust (50-50%)	9 hrs 40 mins	Testing of grass briquettes at 53% load
3/11/99	Rice husk	4 hrs 45 mins	Testing of rice husk briquettes at 33% load
9/1/99	Saw dust	6 hrs 50 mins	Testing of saw dust briquettes at 53% load
12/11/99	Grass and saw dust (30-70%)	7 hrs 35 mins	Testing of grass briquettes at 53% load
20/11/99	Saw dust	6 hrs 35 mins	Testing of saw dust briquettes at 33% load

Table 3.9 Summary of steady state gas composition in various tests

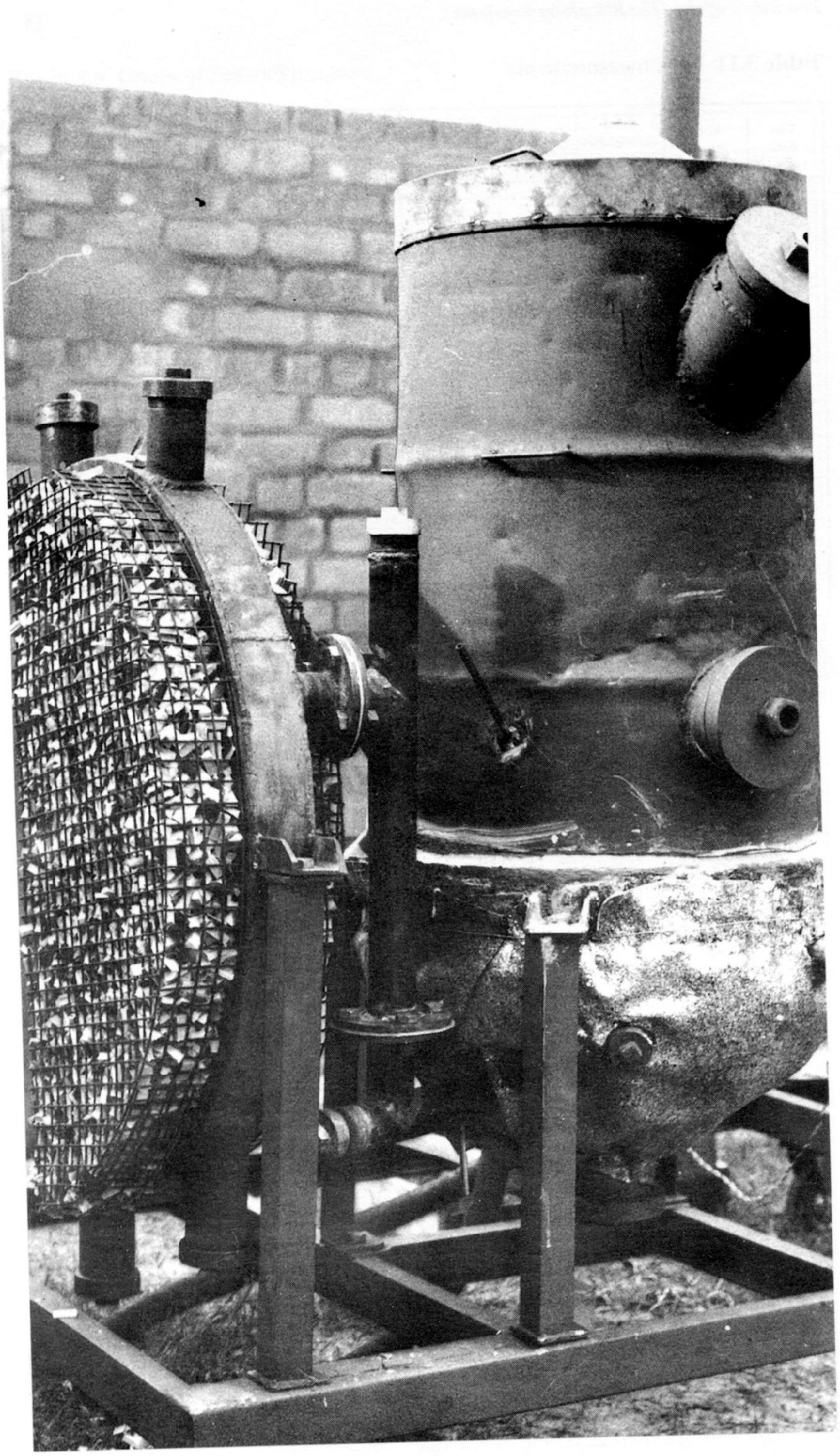
Feed stock	**CO**	**H_2**	**CH_4**	**CO_2**	**N_2**	**O_2**	**m**	**Q (O_2 free basis) MJ/kg**
Restholz	19±1	15±1	0.5	12±1	Rest	1.5	26	3.9
Grass-sawdust (50-50)	22±1	18±1	2	13±1	Rest	0.3	25.1	4.9
Rice husk	12±1	9.5±0.5	2±0.3	14±1	Rest	<2.3	27.6	2.9
Saw dust	24±1	15±1	2±0.5	11±0.5	Rest	0	25.6	5.0
Grass-sawdust (30-70)	22±2	15±1	2±0.5	11	Rest	1.5	25.7	4.8
Saw dust	14±0.5	14±1	3.5	16	Rest	0	26.5	3.8

Table 3.10 Particulate and Tar details

Feed stock	Particulate, mg/m^3		Tar, mg/m^3	
	Hot	**Cold**	**Hot**	**Cold**
Energy grass	19571	408.2	3489	422.0
Restholtz	5087.6	125.95	689.9	70.5
Grass-S (50-50)	484	187	38.28	51.8
Rice husk	495.7	169.7	31.66	9.6
Saw dust (S)	485.89	245	10.7	15.2
Grass –S (30-70)	400.85	272	172.6	5.64
Saw dust (S)	1330	294	348	18

Table 3.11 NOx measurements

Test date	Feed stock	Solid throughput kg/hr (g/s)	Gas flow rate (g/s)	% O_2 in combustion products	T, K	Measured ppmV	Ppm((v) @ 11% O_2	mg/kg NOx on dry fuel basis	mg/MJ NOx on dry fuel basis
Measurements conducted in the burner									
19/2/98	Restholtz	26 (7.2)	18	4.4	823	57	32	442	28
				1.6	823	57	27	373	23
		53 (14.8)	37	6.3	1433	77	49	684	43
				1.6	1523	77	36	503	31
Measurements conducted in the boiler exhaust									
28/10/99	Grass 50%+ Saw dust 50%	38 (10.6)	30	11.4	453	53	56	798	50
				7.3	465	87	60	866	54
				5.0	497	80	47	669	42
				4.0	513	70	38	548	34
03/11/99	Rice husk	21 (5.8)	21	10.5	423	57	54	571	36
09/11/99	Saw dust	39 (10.8)	30	9.3	497	53	44	632	40
12/11/99	Saw dust 70%+ Grass 30%	34.5 (9.6)	30	7.7	513	53	38	545	34
20/11/99	Saw dust	21 (5.8)	21	9.6	466	26	22	320	20
				8.7	503	29	23	326	20



4

Field Tests

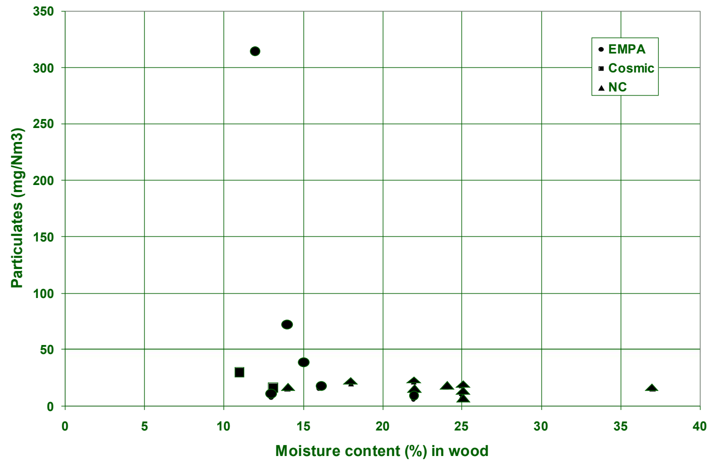
Gasifier Tests in Switzerland

The collaborative effort of IISc, India and DASAG, Switzerland was declared successful with the joint test on the 100 –kWe open top wood gasifier at IISc. Based on the test results and the support from the Swiss Energy Department a similar system was shipped to Switzerland located at Chatel-St.-Denis, closed to Geneva during Nov '95 – March '96. This system had additional automation features like PLC-controlled automatic start-up and shutdown along with instrumentation to record temperatures, static pressures and gas flow rate. The basic intention of this testing effort was to qualify the system for engine application in Swiss conditions using Swiss wood. In the first phase of testing the gas was flared in a burner. The system was tested under adverse ambient conditions (sub-zero temperatures) using different species of wood with moisture content varying upto 37%. The duration of the tests varied from 7 to 9 hrs with tests carried at various loads. Eleven tests were conducted with respect to measurement of gas composition, particulate and tar measurement both at hot (before gas scrubbing) and cold end (after gas scrubbing) of the system. Tests were conducted using casuarina wood (11 - 15% moisture), pine wood (up to 25% moisture), branches (25% moisture) and green wood (up to 37% moisture).

Particulate and Tar analysis

The gas sampling for Particulate and Tar (P&T) analysis was done by IISc and ETH. The P&T analysis was done by Cosmic, India and EMPA and Natura chemica (NC) of Switzerland. There was difference in the results of analysis of the three laboratories and the total particulates were found to vary in the range of 80 - 1020 mg/Nm^3 and 6 - 316 mg/Nm^3 at hot and cold end respectively. The tar at the hot end varied between 46 - 1098 mg/Nm^3 and 5 to 499 mg/Nm^3 at the cold end at varying loads, moisture content and different species of wood. Figure 4.1 shows the results.

There were several tests in which the same sample was analysed by both EMPA and NC agencies. The results of NC agency showed anomalies and some of them had to be discarded. As can be seen from the results , excepting one data point most data show particulate content around 50 ppm or less. Figure 4.1 shows that the tar content has a behaviour that increases in moisture content consistent with the expectations.



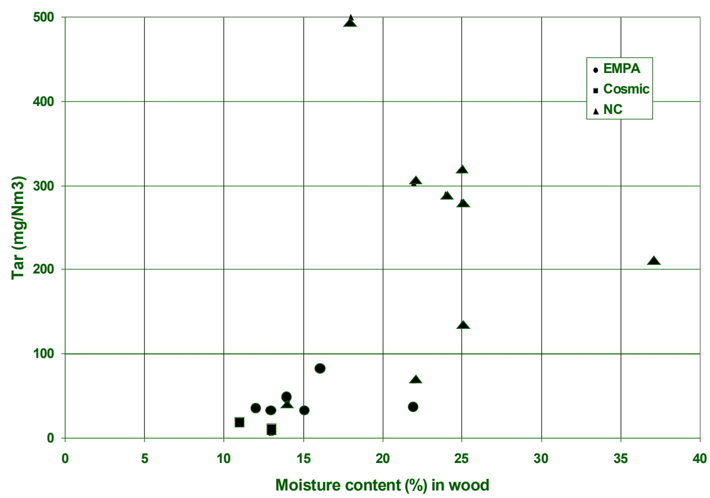


Fig. 4.1 Tar and particulate

Gas composition and Calorific value

The gas composition was obtained using online facilities on to a computer by ETH. The average gas composition was found to be CO 17%, H_2 18%, CH_4 2% and CO_2 13%, the rest being assumed to be Nitrogen with an average calorific value of 4.7 MJ/Nm^3. There was 10% decrease in the calorific value of gas in the case of pinewood. With increase in moisture content, the calorific value of the gas was decreasing. This is because the reactor temperatures are lower with increase in moisture content of wood. Table 4.1 and fig 4.2 shows the variation of gas composition and calorific value with varying moisture content respectively.

Table 4.1: Variation of gas composition with fuel moisture content

Type of Biomass	Moisture content, %	H_2 [v %]	CO [v %]	CH4 [v %]	CO_2 [v %]	Cal Value MJ/Nm^3
Standard wood	13	18.5	16.1	2.3	15.0	4.87
Standard wood	14	17.4	16.7	2.0	14.4	4.7
Standard wood	11	17.6	17.6	2.1	13.6	4.9
Standard wood	13	17.1	16.3	2.3	14.5	4.7
Standard wood	14	18.6	17.4	2.1	14.1	5.0
Pine	15	17.5	17.3	1.6	13.3	4.6
Pine	18	16.5	16.3	1.5	13.2	4.4
Pine	16	16	15.7	1.6	14.4	4.3
Pine	24	15	14.8	1.5	14.7	4.0
Pine	25	16.3	14.6	1.4	15.0	4.1
Branches	25	16.5	13.9	1.1	14.4	3.9
Branches	25	15.3	14.7	1.3	13.0	4.0
Pine	22	15.5	14.3	1.4	13.6	4.0
Pine	25	14.3	13.5	1.3	14.3	3.7
Green wood	37	14	11.2	1.3	15.3	3.4
Pine + Charcoal	25	12.9	13.4	1.5	14.0	3.6

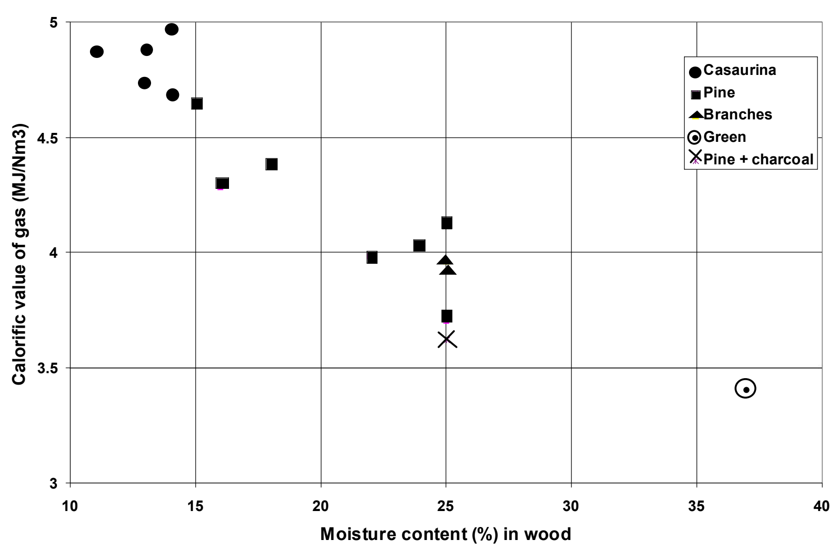


Fig. 4.2 Variation of calorific value of gas with moisture content during tests at various loads

It is clear from the table 4.1 that mole fraction of CO, H_2 and CH_4 steadily decrease with increase in moisture content bringing down the calorific value. On the other hand. Mole fraction of CO_2 and N_2 increase indicating more fuel is combusted inside the reactor for evaporating the moisture. These results further emphasize the need of a drier as an essential element in the system package.

Gasifier tests at M/s Senapathy Whiteley Pvt Ltd. Ramanagaram

The Indo-Swiss joint gasifer testing programmed took a further step with tests on higher power level solid bio residue gasifer at an industrial outfit, M/s Senapathy Whiteley Pvt Ltd. Ramanagaram. The tests were conducted from 23-3-1999 to 21-5-1995 with testing procedure similar to the earlier tests during 1994. Four tests were conducted using two different bio residues. The gasifer system comprised of reactor, cooler, coarse and fine quartz filter, a diesel catalytic convertor followed by a fabric filter. The testing was done in thermal mode, as the load fluctuations in the industry were severe. The parameters that were monitored are reactor wall temperatures, pressure drop across various system elements, biomass consumption rate, gas flow rate, gas composition and the gas quality. Table 4.2 to 4.4 summarizes the test results.

Table 4.2 Test run details

Test No	Date	Biomass	Load (kg/hr)	Run time (hrs)*
1	23/3/99	Causurina rounds	180	6.5
2	25/3/99	Mulberry stalks	144	9.25
3	12/5/99	Mulberry stalks	210	7.5
4	21/5/99	Causurina rounds	210	7.5

* After igniting the gas in the flare

Table 4.3 Average gas composition

Test No	H_2	CO	CH_4	CO_2	O_2
1	11 ± 1	26 ± 1	1.5 ± 0.2	7 ± 1	0
2	14 ± 1	28 ± 1	3 ± 1	12 ± 1	0
3	14.5 ± 0.5	22 ± 1	1.2 ± 0.4	12 ± 0.5	0.3
4	17.5 ± 0.5	15.5 ± 1	1.8 ± 0.2	13.5 ± 0.5	0.3

Table 4.4 Particulate and Tar content in the gas

Test No	Particulate, mg/m^3		Tar, mg/m^3	
	Hot	Cold	Hot	Cold
1	186	46	172	17
2	161	28.5	127.6	13.7
3	189	12.6	156	15.2
4	269	6	116	15

5

Reciprocating engine performance with Producer Gas

Compression Ignition Engines

For the discussions to follow it is assumed that a gas of quality measured in terms of good composition and low particulate and tar content has been obtained from the gasification system. Its use for mechanical power generation (and therefore, electrical power generation) can be in a compression ignition (CI) engine or a spark ignition (SI) engine.

In a CI engine, the gaseous fuel-air mixture is pre-mixed and drawn into the engine via induction system, but some amount of diesel (or a fuel that has good Cetane value, like non-edible oils, for instance) has to be injected into the cylinder to cause ignition of the fuel-air mixture. This is dual-fuel operation. The extent of diesel replacement can be as high as 93%. The 7% liquid fuel is essential for causing ignition and allowing the flame propagation to occur. While this can be achieved in an engine that is called upon to deliver near constant power and the gas composition near constant, it is usually desirable to have a margin to ensure smooth operation – good ignition and ability to take up the load with some fluctuations. This restricts the diesel replacement to about 85 %. If loads were varying significantly, it would be necessary to sacrifice the diesel replacement further. Depending on the extent of variation in the load demand, the average diesel replacement will vary between to 65 to 85%. In operations where the load changes by 100%, one can expect the diesel replacement not to exceed 65%. The true reasons for the lower diesel replacement with load changes are as follows:

When the engine is connected to gas + airline, the diesel replacement is obtained by reducing the amount of air into the engine and allowing more gas to be drawn. Since gas requires air in the ratio of 1:1.2 by volume and with fossil fuels at close to 1: 20, the induction of gas and reduction of a corresponding amount of air will lead to additional energy generation in the cylinder. This leads to instantaneous rise in frequency and the governor will act to reduce the diesel into the engine. This operation of obtaining diesel replacement by reducing the airflow can be managed till a point when the energy inside the cylinder is not adequate to take the load. Then, the frequency will tend to drop and ultimately, the engine stalls. This constitutes the maximum diesel replacement possible. If the engine is tuned to high diesel replacement at relatively high load and then further load is put on, there will be inadequacy of air to combust additional diesel that gets sprayed into the cylinder and hence the engine stalls. It would, thus, be necessary to tune the engine to a lower-than-the- maximum diesel replacement to enable the engine to take on the load. The engine needs to be set at lower diesel replacement at any given load to ensure smooth operation at highly fluctuating loads. It is possible to partly offset this difficulty by having a motorised valve that responds to load changes through a control system, but will turn out to be expensive unless the power level is large.

Thus the operation of a diesel engine in dual-fuel mode is relatively simple. The gas duct is connected to the airline with valves on both the lines or at least one line. Operation of the valve will ensure diesel replacement. While obtaining diesel replacements of 80% even in small engines with dry biomass has not been difficult, achieving 85% has been possible for extended durations of operation with larger capacity engines ~ more than 100 kWe and with near constant load. These data translate to more understandable numbers as follows — a small engine will give about 3 kWh per litre of diesel. In dual fuel mode, 85% diesel replacement implies the number of kWh per litre would be 20 kWh. The amount of biomass used also will vary with diesel replacement. At 60% diesel replacement, biomass required is 0.60 kg/kWh and at 85% replacement, it is 1.0 kg/kWh. Large engines of 200 kWe capacity generate electricity at 3.5 to 3.7 kWh / litre diesel. At 1 MWe, power gets generated at 4.3 kWh / litre. In these cases, one can still get high diesel replacements as per the guidelines noted above.

Engine development and tests on spark ignition (SI) engine

The dual-fuel mode of operations with a diesel engine has two deficiencies. The operator of a small power station (~ 20 to 100 kWe) with varying loads will have to be content with lower diesel replacement. If near constant load is what one needs to deal with, his/her attention gets strained to maintain high diesel replacement without adequate instrumentation that is invariably the case with small power systems. The cost of the fossil fuel in the total energy generation cost will be 30 to 35%. Thus, it would be desirable to examine the option of eliminating the fossil fuel component totally. Such engines need an ignition system since diesel that was causing the ignition is absent. This change does not come without additional investment. The power delivered by the engine in spark ignition mode gets altered by the compression ratio, amount of charge that the engine can take in, the peak temperature that gets attained from the combustion of producer gas – air mixture inside the cylinder, and from the number of moles, decreasing or increasing, during the combustion process (like the combustion of H_2 or CO reduces the number of moles by 0.5 for every mole of the fuel and with CH_4 it remains unaltered). If the engine is derived from a family of diesel engines, the reference power rating will be of diesel engine. If it is natural gas-operated spark ignition engines, the reference power will be of the natural gas engine. Depending on the factors discussed above, the power will get altered, and in fact invariably reduced. The reduction is between 30 to 35%. Thus the effective cost of the engine on per kWe basis will get increased due to this effect. Notwithstanding all these considerations, the enormous cost contribution of the fossil fuel to the total energy cost is a compelling economic drive for developing producer gas-based engines. Typical features affecting the engine performance are described below.

Factors responsible for the engine performance

The calorific value and air-to-fuel ratio will together determine the energy density of a given engine with a specified fuel. As can be noted from the Table 5.1, the energy density of natural gas is the highest, followed by diesel, producer gas and biogas (Biogas is assumed to have 60% methane in this table.

Table 5.1 Properties of various fuels

Fuel	Lower heating value MJ/kg	A/F	Energy density MJ/m^3
Diesel	42.5	18	2.83
Natural gas	45.0	18	3.00
Producer gas	5.2	1.2	2.40
Biogas	23.6	11	2.30

The flame temperature is a more direct indication of the energy content of the fuel. Table 5.2 shows the adiabatic flame temperatures with air at stoichiometry. It can be seen that Producer gas has the lowest temperature. Further, as combustion proceeds, the number of moles decreases due to the creation of products (along the argument made earlier). Both these contribute for achieving lower peak pressure compared to other fuels.

Table 5.2 Adiabatic flame temperature and mole change factor for various fuels

Fuel	T_{adi} (theory), K	Mole change factor	Temperature factor
Diesel	2290	1.0	1
Natural gas	2225	1.0	1
Producer gas	1925	0.86	0.87
Biogas	2160	0.91	0.97

Dasappa (2001) estimates that the change in efficiency is about 3% per unit change in compression ratio in the range of $r_c \leq 12$ and is about 1.8 to 2.4 in the range of compression ratio between 12 and 17. This reduction in efficiency directly leads to loss of power of a similar magnitude. Because of all these considerations, the power output will be the lowest amongst the fuels considered. Specifically, for the Greaves diesel engine, TB 232 that was converted to natural gas and given to IISc for tests on producer gas has been considered by Dasappa (2001) for analysis and the results of the power expected from different fuels in the same engine are shown in Table 5.3. The results obtained in the tests at the laboratory to be described later are consistent with the value for producer gas.

Table 5.3 Power level with different fuels in TB 232 frame

Diesel	Natural gas	Biogas	Producer gas
444 kWe	408 kWe	220 kWe	203 kWe

Even though the above argument indicates that it is desirable to operate an internal combustion engine at the highest possible compression ratio (CR) to attain higher overall efficiencies, the gain in efficiency beyond a certain CR can be expected to be marginal due to other factors as heat loss and friction. In the case of a SI engine, the limitation of CR comes from the knock sensitivity of the fuel. It has been experimentally investigated that the upper limit for compression ratio for SI engine operation is 17:1 beyond which there is a fall in efficiency. The above conclusion is based on extensive tests with iso-octane as the fuel also doped with anti-knock agent. If one were to consider this as the upper limit and since no other work has been conducted at higher CR for SI engines, choosing a production engine in the above range for the current investigation seemed very appropriate

The current investigation was conducted on a commercially available diesel engine so as to explore the possibility of working at existing CR of 17 and optimizing the same if required. At the onset of investigation, it was perceived that increase in CR could have conflicting effects on the power output of the engine. This could be explained as follows:

It has been universally recognised that turbulent flame speed plays a vital role in the heat release rate during the combustion process in an engine cylinder. The turbulent flame speed can be treated as an enhanced form of laminar flame under the influence of time varying turbulence within the combustion chamber of the engine. The laminar flame speed is again a function of initial pressure, temperature and the mixture composition. An earlier computational work by Mishra et al (1992) indicated that the laminar flame speed for stoichiometric producer gas and air mixture could decrease by one-tenth as the initial pressure is enhanced by a factor of 40. However, these calculations were made at an initial temperature of 300 K, and the initial temperature at which combustion starts is high in the case of internal combustion engines. The influence of initial pressure and temperature on laminar flame speed can be explained in simple terms as follows. The increase in unburned gas temperature results in increase in adiabatic flame temperature and hence the average reaction rates. The increase in the reaction rate is a result of the increase in the number of radicals released, thus, contributing to increase in the flame speed, whereas the rise in pressure can result in reduction in the amount of radicals released thus retarding the flame speed. Therefore the conflicting nature of the effects of initial pressure and temperature needs to be recognised. The effects of these at varying CR are an additional feature affecting the optimum CR. Consequently, the present investigation was started with an assumption that optimum compression ratio would be between 12 and 17 for maximum power output and overall efficiency.

In the study collected at the laboratory, CR was the parameter that was varied. The influence of CR on power, efficiency and emissions has been studied in some detail. Minimum ignition advance for best torque (MBT) has been determined at different CRs. The variation of cylinder pressure with time has been captured using a Piezo-based transducer. The overall energy balance has been projected.

Producer Gas Engines

The work on 100% producer gas fuelled engines was initiated at IISc way back in 1997, since then there has been substantial progress made in this area. Initial work was commenced by addressing the smaller capacity engines, which were essentially converted from commercially diesel engines. Since the work involved was of scientific nature it called for measurement of a number of parameters that helped in understanding the engine combustion phenomenon. The study also involved modelling work, which could predict engine performance over a range of operating conditions. As a further logical extension, a similar capacity gas engine (RB-33 diesel engine converted to gas engine) has been deployed for field operations at a nearby site in Bangalore and has clocked about 2000 hours without any major intervention.

The medium capacity engine is essentially an extension of the earlier work; where in major findings are successfully applied. Of the three engines tested, one belonged to Greaves make and other two of Cummins make. These engines arrived for testing as gas engines, design to operate on bio-gas/natural gas. The engines were successfully adapted to operate of producer gas, wherein the design and development of gas carburettor for producer gas fuel was a major milestone. The engines have been tested in excess of 200 hours at the laboratory and optimum control parameter namely, ignition advanced identified. The design of the necessary hardware items, namely, the pressure regulator and the gas carburettor have been clearly identified and has reached a stage wherein there is clarity established for adapting of any gas engine for producer gas operation. Details of this part of development activity is as follows.

Small Power Level Gas Engines

A 20-kWe–diesel engine (RB-33 model) is converted to operate on producer gas. The development efforts in adopting a 20-kWe rating compression ignition engine with necessary modifications to operate on producer gas alone is discussed here.

Conversion methodology

A three cylinder (refer Plate – 1), direct injection diesel engine of 3.3 litres capacity, with a CR of 17:1 was converted into a spark ignition engine to drive a 25-kVA alternator. The salient features of the engine are given in Table – 5.4. Modifications attempted on the engine for conversion are as follows:

1. Insertion of spark plug in place of fuel injectors without changing its location (centrally located).

2. Adaptation of a distributor type battery-based ignition system with a provision to advance/retard of ignition timing. The set ignition timing was checked using a stroboscope.

3. The combustion chamber design comprising a flat cylinder head and bowl-in piston was retained. No attempts were made to change the combustion chamber design except that the thickness of the cylinder head gasket was varied to accomplish different CRs of 17, 14.5, 13.5 &11.5.

4. For in-cylinder pressure measurement, provision was made on one cylinder head by drilling a 1.5mm diameter hole for pressure measurement and fitting an optical sensor on the crankshaft for crank angle measurement.

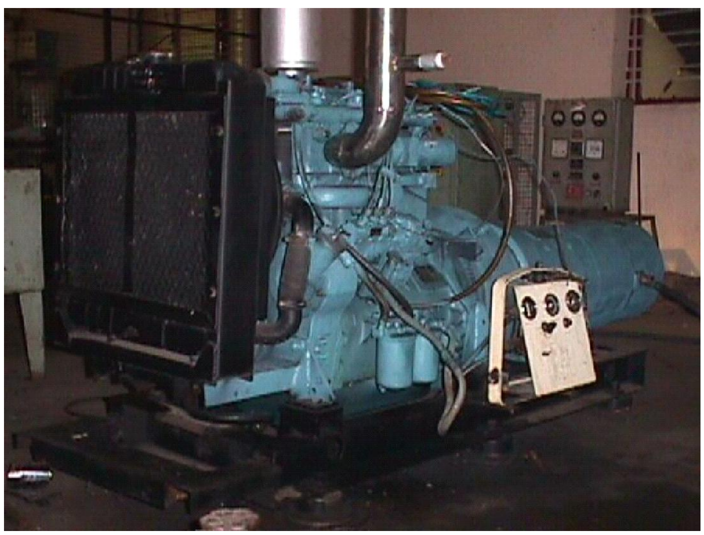


Plate 5.1 Photograph of producer gas engine converted from RB-33 model diesel engine

Table 5.4 Small Power level Engine (SPE) Configuration Details

Parameter	Specification
Make and Model	Kirloskar, RB-33 Coupled to a 25kVA Alternator
Engine Type	In-Line, 3 Cylinder, 4-Stroke, Naturally Aspirated
Rated Output - Diesel	28 kW @ 1500 rev/min
Net Output - Diesel	24 kW (21kWe) @ 1500 rev/min
Type of Cooling	Water Cooled with Radiator
Bore x Stroke	110 x 116 mm
Swept Volume	1.1 Litre
Compression Ratio	17:1
Bumping Clearance	1.5 mm
Combustion Chamber	Flat Cylinder Head and Hemispherical Bowl-in Piston Type
Squish Area	70%
Ignition System - Gas	Battery Based Distributor Type with Ignition Advance/Retard Facility
Spark Plug Type & Location - Gas Mode	Cold, Offset from the Axis of Cylinder by 8mm
Intake Port	Directed Type
Valve Timing	Inlet Valve Opening – 26 ° BTC Inlet Valve Closing – 66 ° ABC Exhaust Valve Opening – 64 ° BBC Exhaust Valve Closing – 38 ° ATC
Firing Order	1-2-3
SFC, g/kWh - Diesel	280 - 290
Air-to-Fuel Ratio - Diesel Mode at Peak Load	20 to 21:1 at 24 kW
Alternator Efficiency	87%

BTC: Before Top Center, ABC: After Bottom Centre, BBC: Before Bottom Centre, ATC: After Top Centre

The experimental scheme

The well-researched, tested and industrial version of IISc's-open top reburn down draft, twin air entry 75 kg hr^{-1} solid bio-residue gasifier system formed the gas generator. The overall details of the gasifier system are presented in the Figure 5.1. As shown in the figure, the system had provision to test the quality of the gas prior to supply to the engine. At the engine intake, a carburettor is provided for proportioning air and fuel flow. As there were no carburettors commercially available to cater to producer gas, a locally made carburetion system and manually controlled valve were used for proportioning.

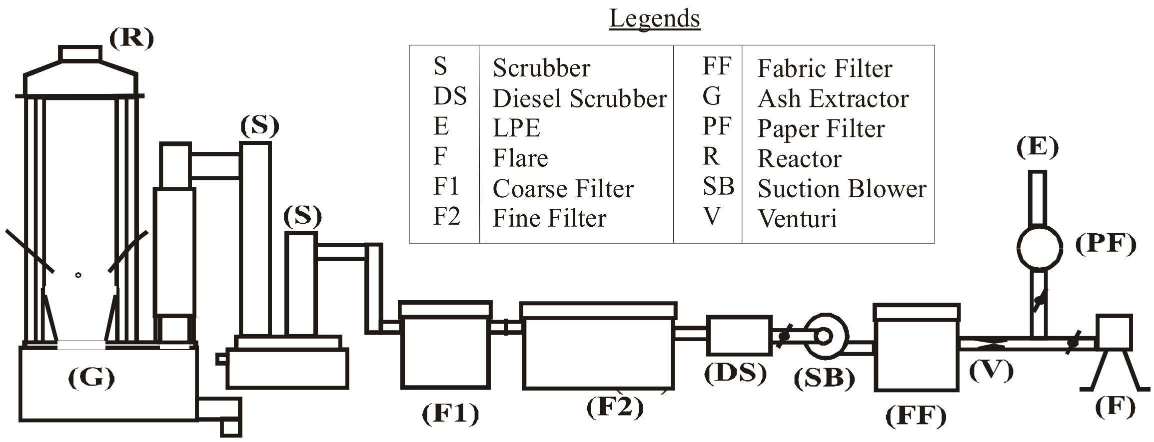


Fig. 5.1 Schematic of Open Top Re-burn Gasifier Connected to SPE

Measurements were made with respect to the following parameters

A. Producer gas compositions using on-line gas analysers. The gases analysed were CO, CO_2, CH_4, O_2 and H_2. The N_2 concentration was deduced by difference. The CO, CO_2, CH_4 components were determined using infrared gas analysers and the H_2 component using a thermal conductivity based analyser. The O_2 measurement system was based on chemical cell.

B. In-cylinder pressure variation data synchronised with the crank angle measurement was acquired on a computer for every one-degree crank angle. The pressure measurement was accomplished using a pre-calibrated Piezo-based pressure transducer (M/s PCB make).

C. Measurement of voltage and current across three phases and frequency for power output calculations – the load bank constituted of resistors.

D. Air and gas flow to the engine using pre-calibrated venturimeters

E. Engine exhaust analysis - O_2, CO_2 CO, and NO and temperature

Experimental Procedure

Experiments were initiated on the engine only after the gasifer system stabilised i.e. attained steady state operation in terms of generation of consistent quality gas. Typically time scale for attaining steady state of operation from the cold start was 2 to 3 hours. During this period the gas was flared in a burner. The gas composition was determined using on-line gas analysers, pre-calibrated using a known producer gas mixture. The calibrations of these analyser were checked at a random time intervals so as to minimise errors in long duration operation. Typically gas composition at the time of strait of engine test was 90 ± 1% - H_2; 90 ± 1% - CO; 2% - CH_4; 12 ± 1% - CO_2; 2 ± 0.5% - H_2O and rest, N_2. The mean calorific value of gas varied around 4.65 ± 0.15 $MJNm^{-3}$. The feedstock used for gasification is causurina species wood moisture content between 12 to 15% on dry basis (sun dried wood).

Once the gas composition stabilized, the engine was operated for a few minutes at 1500 RPM at no-load condition. All the tests on the engine were conducted around constant speed of 1500±50 RPM. The throttling for speed control and air and fuel proportioning was achieved using manually operated valves.

Experiments were conducted at CRs of 17:1, 14.5:1, 13.5:1 and 11.5:1 and these CRs were achieved by varying the thickness of the cylinder head gasket. The compression ratio values are based on cylinder's geometric measurements and were verified by matching the motoring curve with an engine simulation curve. The engine was tested at different ignition timing settings to determine the MBT at different CRs. With set ignition timing, the air and fuel were tuned to achieve maximum power.

Results

Performance

The first and the foremost result of these tests is that the engine worked smoothly without any sign of knock at high CR of 17:1. There was no sign of audible knock during the entire load range. Moreover, the absence of knock was clear from the pressure-crank angle recordings both at full load and part load.

The result of the power output with producer gas are shown in Table 5.5. At CR=17, the engine delivered a maximum net brake output of 20kW (17.5 kWe) at an efficiency of 30.7% compared to 24kW (21kWe) brake output 33% efficiency with diesel (compression ignition mode). The efficiency calculation is based on the ratio of net brake output to the energy content of the air and gas mixture. The useful output and efficiency decreased with the lowering of CR. A maximum net brake output of 17.6 kW (15.3 kWe) at an efficiency of 27.5% was obtained at CR of 11.5. The power output at intermediate CR of 14.5 and 13.5 were 18.8 and 18.6 kW respectively and with efficiencies around 29%. The efficiency at CR=13.5 was comparable to that at 14.5 probably due to relatively leaner operation. The extent of de-rating in brake power was about 16.7% at CR = 17 and increased to as high as 26% at CR=11.5 compared with baseline operation in diesel mode.

Table 5.5 Maximum Net Engine Output at Varying CR

CR	IGN, BTC	Φ	Net Elec. Power, kWe	Net Brake Power (BP_{Net}) , kW	Mixture Energy Density, MJ/kg	Efficiency : Gas-to-Shaft, %
17.0	06	1.10	17.5	20.0	2.20	30.7
14.5	10	1.10	16.4	18.8	2.20	29.0
13.5	14	1.06	16.2	18.6	2.10	29.3
11.5	15, 17	1.07	15.3	17.6	2.20	27.5

Φ =Equivalence Ratio: (Actual fuel- to- air ratio)/(Stoichiometric fuel- to- air ratio)

The incremental gain in maximum power and efficiency per unit CR is shown in Table 5.6. The gain in power was between 2.2 and 2.6 per unit CR, but the gain in efficiency was marginally lower. However, these figures are well within the range of 1 to 3 % gain per unit increment of CR reported in literature.

Table 5.6 Incremental Gain in Power and Efficiencies

Range in CR	Gain in power/CR, %	Gain in efficiency/CR, %
14.5 to 17.0	2.60	2.3
13.5 to 17.0	2.20	1.4
11.5 to 17.0	2.50	2.1

Next, the variation of mechanical efficiency (ratio of net brake power to gross indicated power), η_{mech} with CR is shown in Table 5.7. These values are deduced from indicated power measurements (based on integration of pressure-volume diagram) and not output measured, also values obtained from standard multi-cylinder Morse test are shown in Table 5.7. The η_{mech} of the engine at CR are 17 is about 80% and increase to as high as 87% at CR of 11.5. The increase in η_{mech} is attributed to the deduction in a rubbing friction due to lower cylinder pressures encountered at CRs.

Table 5.7 η_{mech} Measurements

CR	η_{mech} from $\int pdV$	η_{mech} from Morse test
17.0	80-82	81 $\pm$ 1
14.5	84-86	84 $\pm$2
13.5	85-88	86 $\pm$2
11.5	88-90	88 $\pm$1

Pressure –Crank angle data

The pressure-crank angle recording at all the CRs did not show any trace of knock for all ranges of load inclusive that of peak load and this is visible from the pressure-crank angle diagrams as shown in the Figure 5.2. Faster burn rate due to presence of hydrogen in the fuel gas may be one factor for the non-knocking performance at higher compression ratio. The faster burn rate accompanied by retarded ignition timing setting obviates any auto-ignition tendency of the end gas. Increasing the flame speed or retarding the ignition timing setting is one possible way of reducing knock tendency and this is well acknowledged in the literature.

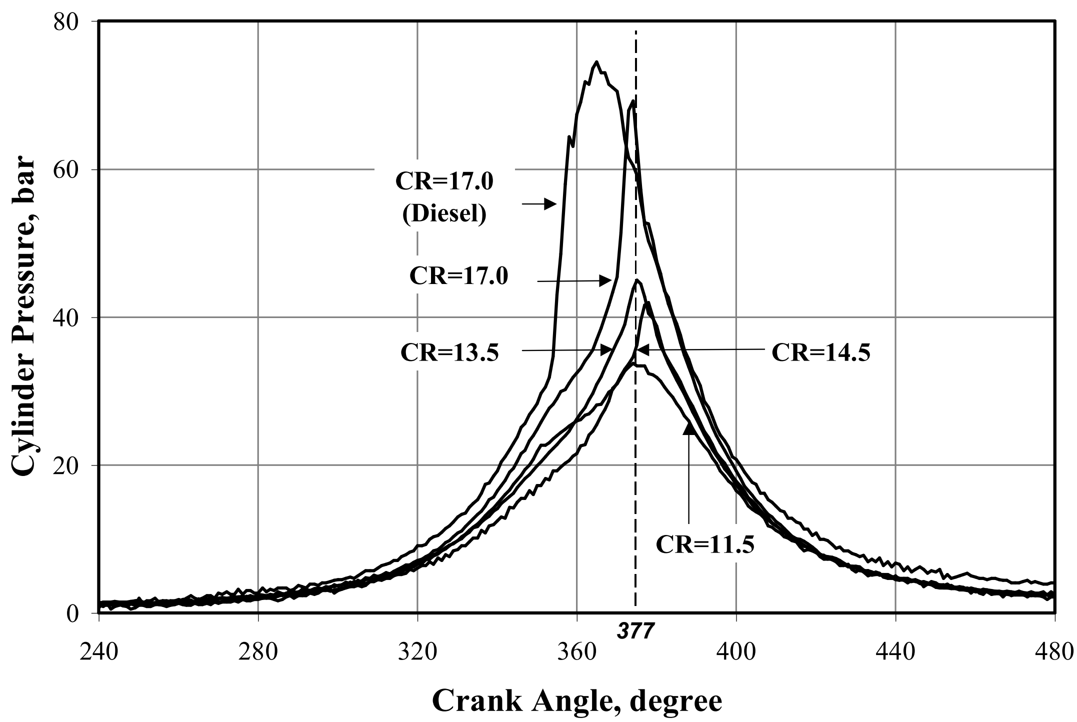


Fig. 5.2 Comparison of p-θ Curves at Different CR; Ignition Timing is at MBT or Close to MBT (Within MBT + 2° CA). The p—θ curves correspond to ignition setting of 10°, 10°, 14° and 15° BTC for CR of 17, 14.5, 13.5 and 11.5 respectively. Operation in Diesel Mode at 90% of rated Load (at Optimum Injection Timing - 34° BTC). All are Ensemble-Averaged Data Over 30 Consecutive Cycles.

The network delivered over a complete cycle can be found by integrating the pressure-volume (p-v) data over the four processes. This also helped in identifying the optimum ignition timing for a given CR - commonly referred as MBT. The net indicated mean effective pressure (IMEP) obtained from the integrated p-v data is a measure of effectiveness with which an engine of a given volumetric displacement converts the input energy into useful work. The IMEP obtained from ensemble average p-v data (~ 30 cycles) at varying CR as a function of ignition timing is shown in Figure 5.3. At CR = 17, the maximum IMEP recorded is 5.98 bar corresponding to a ignition timing of 6° CA and this declined to 4.85 bar with ignition timing being 15° CA at CT of 11.5. These values are obtained at ϕ = 1.08 ±0.2 and fall within the anticipated value of ϕ = 1.0 to 1.1. It is also evident from the plot that variations in the IMEP values are modest between ignition timings of 6 and 12° CA corresponding to CR=17.

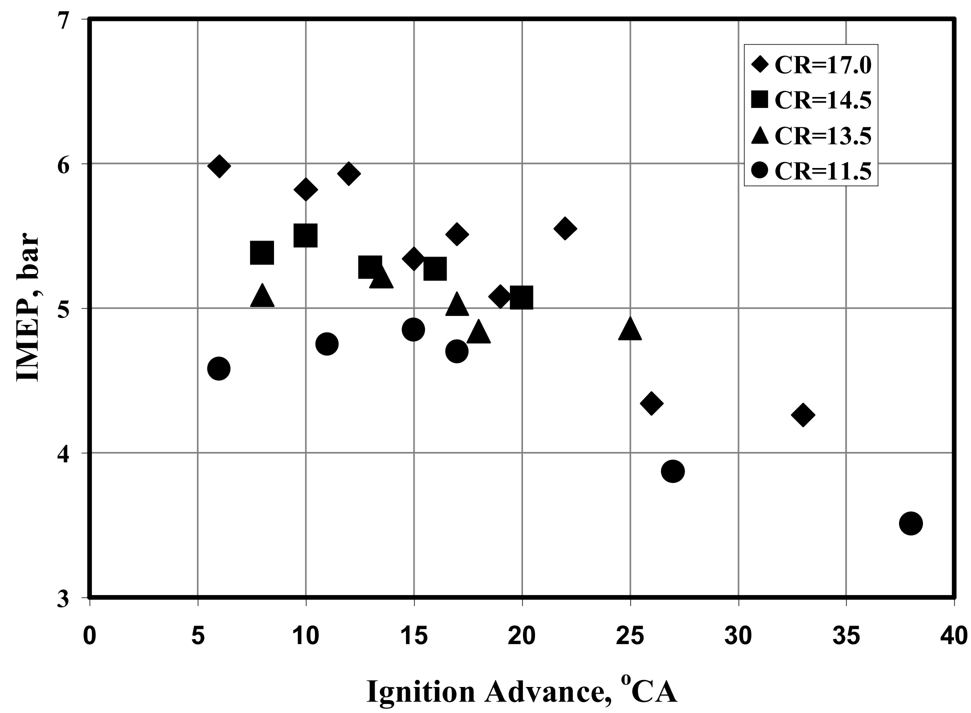


Fig. 5.3 Variation of IMEP (Net) with Ignition Advance at Various CRs

Exploring further the p-θ data, the peak pressure and the point of occurrence at ignition timings close to MBT are listed in Table 5.8. These measurements are accurate within – 1.0° CA (due to positive lag in the signal and error in TC identification). IT is evident from the data that peak pressure seem to occur between 17 and 19° ATC (After Top Centre) at all CRs. In the case of CR = 13.5, the peak pressure seemed to occur at the optimum value (17° ATC) identified in the literature. In the case of CR = 11.5, the peak pressure occurred at 17 and 12° ATC for an ignition timing of 15 and 17° BTC respectively. The difference in the IMEP between the two ignition timing was found to be 3%. However, for CR of 17 and 14.5 the ignition timing identified in the Table 5 seemed to be marginally deviating from the optimum value. The variation of IMEP within this close range would be marginal as it is well acknowledged that the relative torque delivered has a flatter characteristic around MBT.

Table 5.8 Cylinder Peak Pressures and Their Occurrence

CR	Ign. advance ° CA	Peak pressure, bar	Occurrence ° ATC
17.0	6	55.00	20
14.5	10	43.30	19
13.5	14	45.00	17
11.5	15, 17	33.00, 38.00	17, 12

The coefficient of variation of the IMEP at all CRs and ignition settings occurred well within 3- 3.5%, as shown in the Fig. 5.4 implying low cycle- to-cycle variation. The reason for low cyclic variation is the faster rate of combustion occurring inside the engine cylinder. The faster rate of combustion is attributed to higher flame speeds due to the presence of hydrogen in the gas and also to the combustion chamber design.

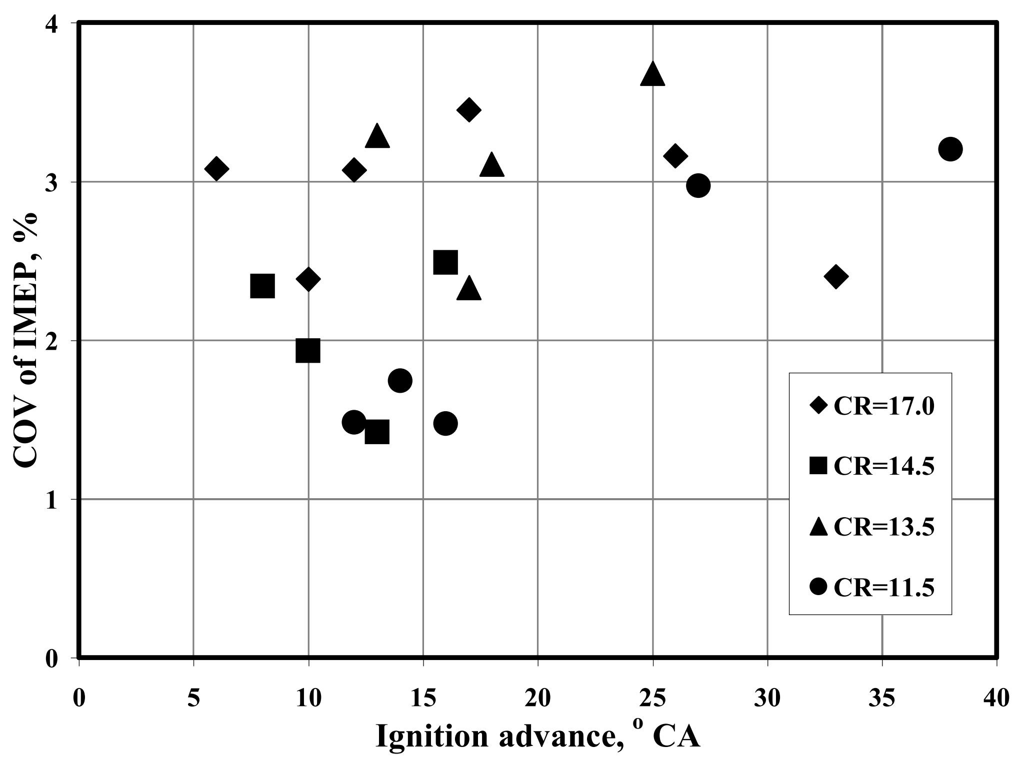
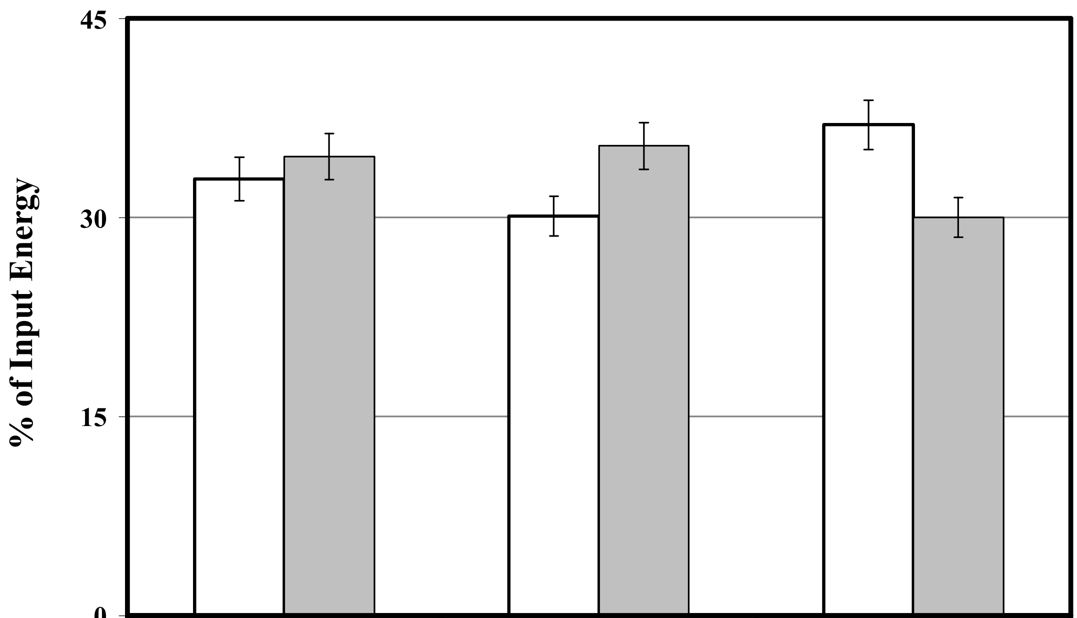


Fig. 5.4 COV of IMEP (Net) with Ignition Advance at Various CRs

Energy Balance

Figure 5.5 represents the overall energy balance at CR=17. The energy balance is based on gross brake power output. The gross brake output is sum of net shaft output and power consume by engine accessories (water pump/fan, dynamo and FIP=1.4kW). The energy balance in gas mode corresponding to maximum brake output (at 6° CA) showed a useful output (gross brake power) of 32.9%, about 30% is lost through exhaust (sensible and chemical enthalpy – CO) and remaining 37% to the cooling water (inclusive of frictional and radiative losses). Figure 5.5 also compares the energy balance in gas and diesel mode (at rated output of 24kW) at CR of 17, the energy loss to the coolant and miscellaneous is about 37% compared to 30% in diesel and whereas, energy loss through exhaust is lower by about 5% in gas mode. Overall the brake thermal efficiency is lower by about 1.5% in gas.



	Gross brake output	Exhaust	Coolant & Miscl.
PG	32.9	30.1	37.0
Diesel	34.6	35.4	30.0

Fig. 5.5 Energy Balance Comparison in Diesel and Producer Gas Mode at Maximum Brake Output. The Marker Refers to the Error Band

Emissions

The emissions measured are Nitric Oxide (NO) and Carbon Monoxide (CO). The variation of NO in gas mode at varying CR with ignition advance is shown in Fig 5.6. NO_2 was not accounted as it forms small part (~ 5%) of NOx generated. The NO level has been represented as an emission index in units of gram per unit MJ of input energy. These results are compared with the CPCB norms (equivalent to EURO I norm) meant for diesel engine powered vehicle, as there are no existing CPCB norms for stationary engines. Similarly, there are no norms existing for small power level (< 2.0 MW) stationary engines, therefore, existing diesel vehicular norms of CPCB are stated for comparison. Also the data is compared with the Swiss emission norm, as it is generally understood that their norms are stringent. The NO level reduced with the retardations of ignition timing and this features if observed for all CRs. The NO level is observed to be maximum a the highest CR with advanced ignition timings, whereas in the MBT range of 6 to 20°BTC the NO is lower and comparable in almost all the cases. It is well known that NO generation is strongly dependant on the temperature oxygen availability and residence time in the combustion chamber. With the flame speed of the gas mixture being high, the ignition setting is retarded whereby the residence time in the high temperature combustion chamber is automatically reduced. Therefore the low NO levels at retarded ignition setting are an expected and consistent behaviour. The above results match well with those quoted in the literature, which show small to modest variation of NO with CR. The NO emissions are lower than the CPCB and Swiss norm for all cases around MBT.

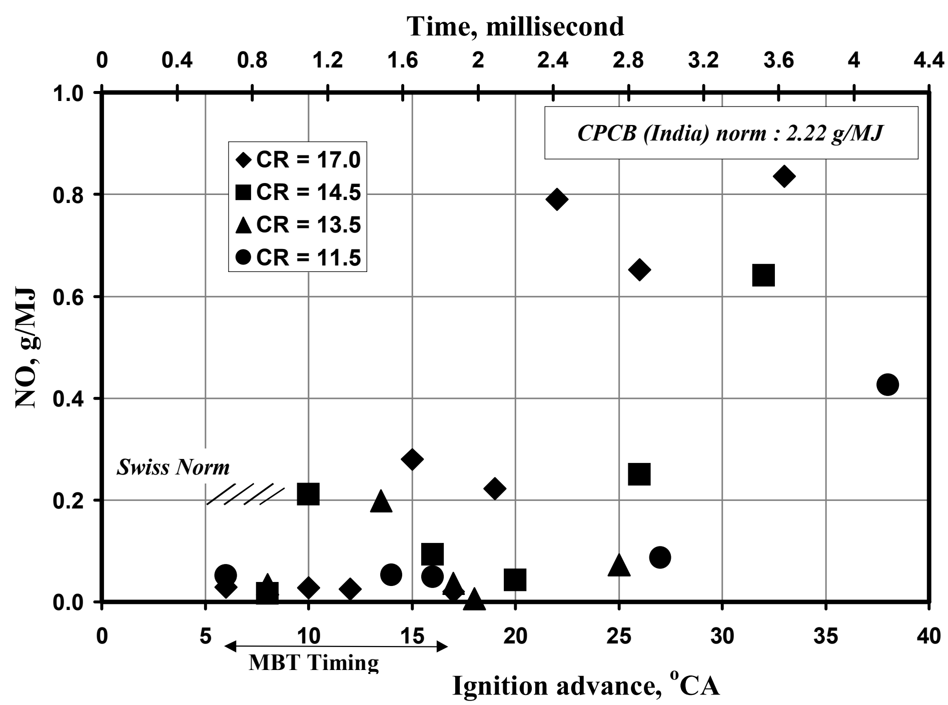


Fig. 5.6 Variation of NO with Ignition Advance at Various CRs

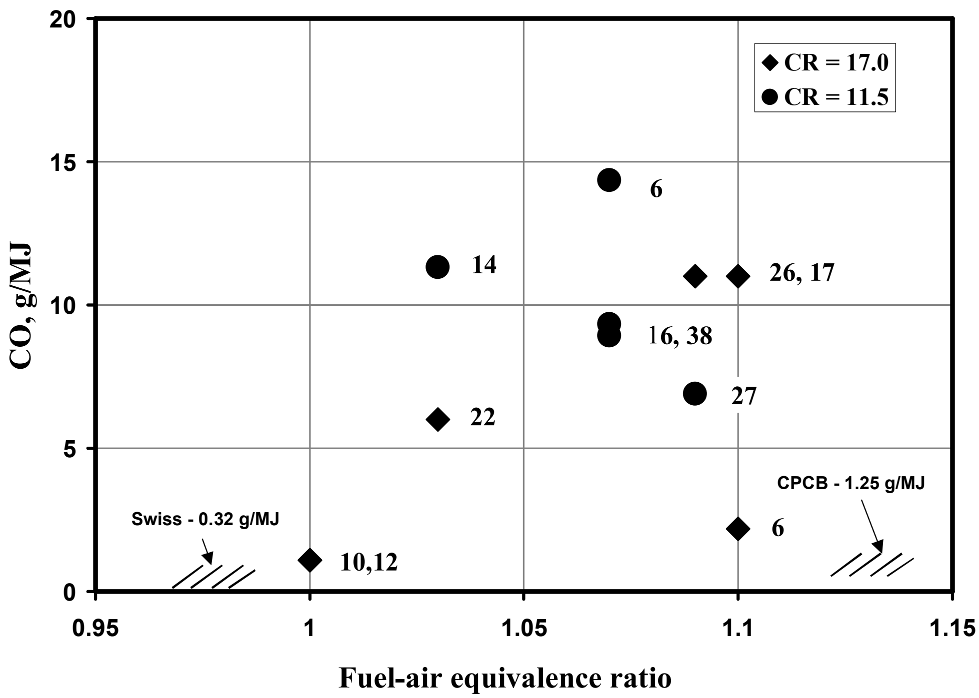


Fig. 5.7: Variation of CO with Fuel-Air Equivalence Ratio. The Number Next to the Legend Indicates the Ignition Advance in ° CA, BTC.

The variation of CO with equivalence ratio (ϕ) is shown in Figure 5.7. The CO levels are represented in grams per MJ of input energy. The trend of CO with ϕ is clear from the figure. The CO levels were lower at the highest CR as well as fuel lean conditions, and this could be attributed to higher temperatures, leading to relatively complete combustion. Overall, the levels are found to be much higher than the CPCB and Swiss norm. One may not require a catalytic convertor in the exhaust for reducing CO in the operations are at slightly leaner conditions.

Long Duration Trials

In order to establish reliability in gas engine operation, long duration tests were conducted in the month of April 2000, wherein the gas engine was operated in a continuous mode for 100 hours duration. The engine was set at CR of 17 and operated close to rated condition (16 – 17 kWe). There was change made in the gas engine hardware as compared to the one employed for short duration trails. This is with respect to enhancement of the cooling fan and radiator capacity. This was done in order to preventing overheating of the engine due to larger fraction of heat loss to the coolant in gas mode of operation. The radiator and cooling capacity was virtually doubled as compare to original configuration in the diesel engine. This enhanced cooling system reduced the engine net output by about 1.0 kWe.

The engine operation was found be satisfactory without any major interventions for stoppage. At the end of successful run of 100 hours, the engine was stripped open and the combustion chamber was found to be clean without any carbon deposits. In fact the carbon deposits were very much marginal when compared to engine run on diesel further same no. of hours. One interesting outcome of these trials is the specific biomass consumption and this turn to be 1.25 + 0.5 kg/kWh.

Field Trials

In continuation of the laboratory trials, a similar capacity gas engine was deployed for field trials at a farm house close to Bangalore namely, Dewan Estate at Bethamangala, Kolar District, Karnataka. The gasification power plant has been installed and commissioned by Netpro Renewable Energy (India) Ltd., Bangalore in May 2000 and the gas engine in August 2000. The gas engine formed a part of the 50 kg/h rating gasification power plant meant for power generation to meet the irrigational need of the farm. The gas engine was supplied with additional cooling capacity as mentioned earlier and reduced the engine net output by about 1.0 kWe. Therefore, the gas engine is rated for a maximum output of about 15-16 kWe.

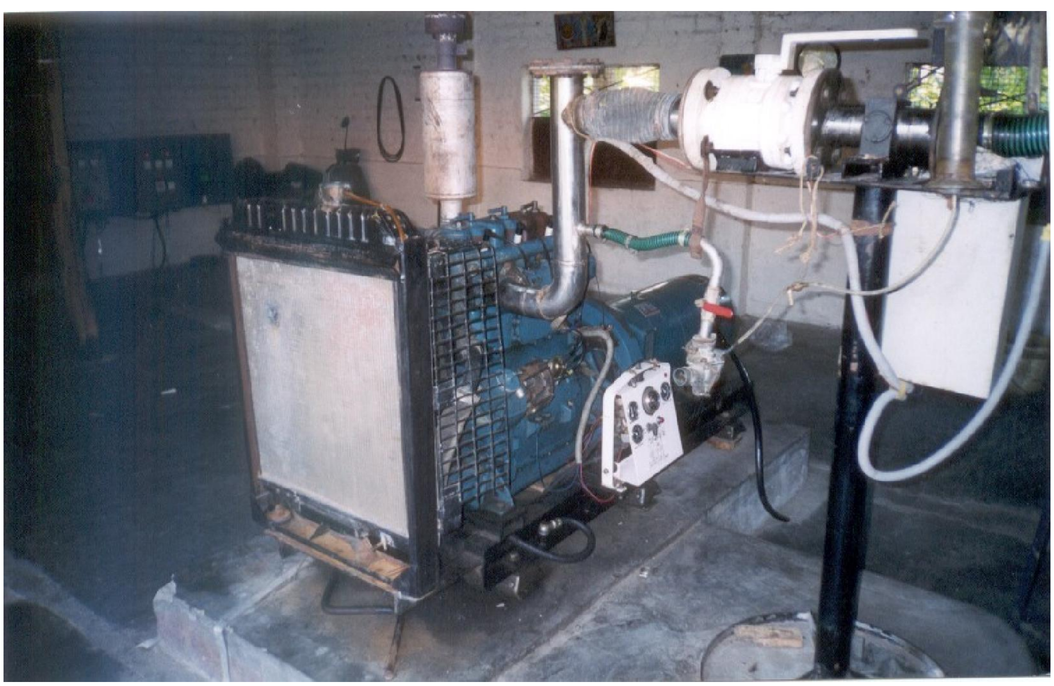


Plate 5.2 Producer gas engine at Dewan Estate, Bethmangala, Kolar District, Karnataka.

The gas engine has been rated to deliver a peak power (delivered useful power) of 13.5 to 14.0 kWe. Some of the engine parameters like the ignition timing have been tuned to provide a smooth operation over a wide range of operation conditions. This has been considered because of the possible variations in gasifier operation at the field level. This could arise either from or a combination of these factors, namely, use of higher moisture content (higher than 15-20%) feed stock, short spells of operation (less than one or two hours) with prolonged duration of shut-down-sum sort of a stand-by operation. In the current case the later seem to be more dominant from the information available to us. This sort of stand by operations will have an implication on the gas quality in terms of its composition and thereby affect the net power delivered. Some aspects of the engine performance have been reflected in two figures, Fig. 5.8 shows the specific biomass consumption against several days of operation. The Fig. 5.9 which shows the number of Units generated month wise.

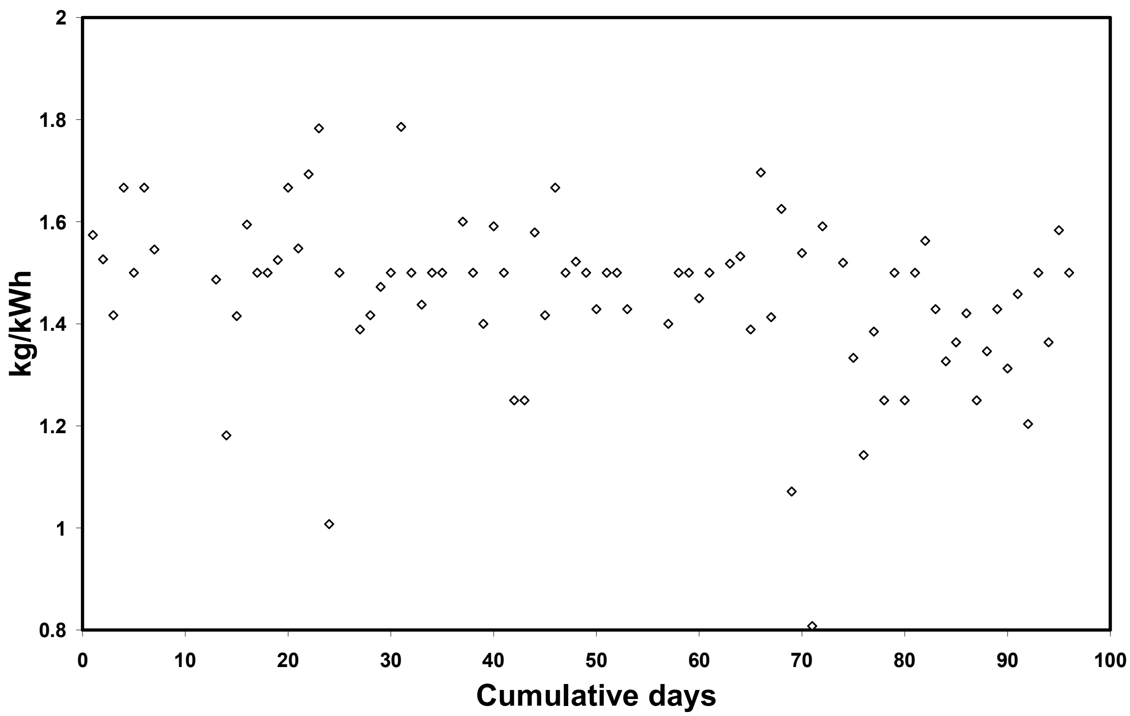


Fig. 5.8: Specific Biomass Consumption Data from Field Trials

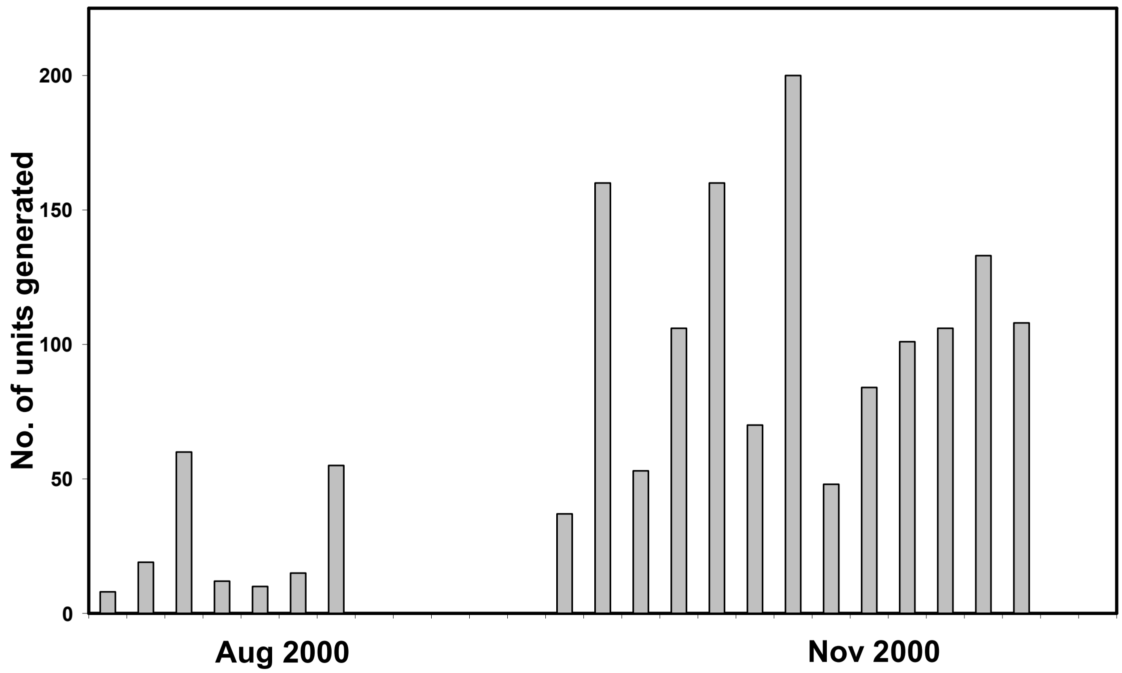


Fig. 5.9: Record of No. of Units Electricity Generated Month Wise

Medium Power Level Gas Engines

Under this category three gas engines from two different manufacturers have been tested. One belongs to Greaves Limited, Pune and other to Cummins Indian Limited, Pune. These engines are commercially marketed as bio-gas and natural gas engines and therefore the work involved more of an adaption to suit for producer gas fuel. Therefore, no modifications were attempted on the engine per se, however, there has been substantial work than in terms of development of components like the gas carburettor for producer gas fuel. The details of adaption and subsequent trials are explained in the following sections.

1. Greaves Engine

The understanding gained from the experimental work on the SPED engine is translated onto the medium power level engine (MPE) and its performance accessed on producer gas. The gas engine chosen for experiments is a 12 cylinder (V-configuration) turbo-charged-after cooler engine, supplied originally to operate on dilute natural gas (biogas fuel). These brand engines are marketed as bio-gas engines and are serving as days load power plants in many parts of India. This engine is adopted to operate on producer gas along with a specially designed gas carburettor. The detailed specification of the engine is given in Table 5.9. This engine is basically built from a diesel engine frame (model no. TBD4V12, rated at 444 kW at CR 15) at a modified CR of 12, to operate on gaseous fuels in a spark-ignited mode. The other modifications implemented in the engine are with respect to turbo-charger (model K-28 in place of K-36) and combustion chamber (simple cylindrical bowl in place of torroidal shape). The K-36 and K-28 turbo-charger are designed to generate a pressure ratio of 2.2 and 1.5 – 1.6 respectively. Therefore, the estimated power rating of the modified engine in diesel is between 219 – 310 kW. The modified engine (to operate has a SI engine) was initially equipped with double sparking ignition system, where in a redundant spark occurred during the exhaust process. It so happened that whenever the engine was operated with an ignition timing coinciding with a valve overlap period, a backfire occurred into the engine intake. This therefore limited available range of the ignition timing for testing purposes. Problem was subsequently resolved by replacing with a single sparking ignition system, which permitted engine operation over a wider range of ignition timing.

Table 5.9 Medium Power level Engine Configuration Details

Parameter	**Specification**
Make and Model	Greaves, Coupled to a 300 kVA Alternator
Engine Type	12 Cylinder, 'V' Configuration Gas Engine, Turbo-Charged with After Cooler
Rated Output - Diesel	290 – 310 kW (Estimated) @ 1500 Rev/Min
Rated Output – Diluted Natural Gas (Bio-Gas)	250 - 270 kW @ 1500 Rev/Min (Achieved)
Type of Cooling	Water Cooled with Radiator
Bore x Stroke	128 x 140 mm
Swept Volume	1.8 Litre
Compression Ratio	12:1
Bumping Clearance	1.6 mm
Combustion Chamber	Flat Cylinder Head and Bowl-in Piston
Squish Area	68%
Ignition System	Gill Instruments – Single Sparking Unit with Individual Coil for Each Cylinder
Governor	GAC Make
Spark Plug Type & Location	Cold, Offset – Located in the Vertical Plane Close to the Outer Edge of the Bowl
Intake Port	Directed Type
Valve Timing	Inlet Valve Opening – 12° BTC Inlet Valve Closing – 55° ABC Exhaust Valve Opening – 44° BBC Exhaust Valve Closing – 15° ATC
Firing Order	A1, B5, A5, B3, A3, B6, A6, B2, A2, B4, A4, B1
SFC, m^3/kWh – Bio-Gas	0.3
Alternator Efficiency	92%

BTC: Before Top Center, ABC: After Bottom Centre, BBC: Before Bottom Centre, ATC: After Top Centre

The combustion chamber is formed for a flat cylinder head and a bowl in piston. The bowl is cylindrical in shape and has a squish area of 68% (percentage of piston area closely approaching the cylinder head at the smallest spacing). The spark plug is located at an offset in the vertical plane close to the outer edge of the bowl. The single spark type electronic ignition unit comprised of a controller, Hall effect sensor, and individual ignition coils, wiring harness and spark plugs. The ignition timing was precisely controlled by interfacing with a computer to within one-degree crank angle. The engine coupled with a standard alternator was connected to a load bank (resistor coils) to facilitate load tests. The mixture (air+gas) intake system comprised of an air filter, turbo-compressor, after cooler, mixture controller – gas governor, manifold and runner to each cylinder head.

A 250-kg/hr-biomass gasifier formed gas generator with the system elements in terms of gas cleaning system different compared to the 75-kg/hr system. The gasifier-engine system is shown in plate-3. Since the engine of reasonably higher power level, the air-to-fuel control to load variation assumed a major preposition. This called for design and development of a gas carburettor for producer gas application, as carburettors are not available for producer gas fuel. The carburettor available for other gaseous fuel, namely the natural gas, biogas and landfill gas are unsuitable due to widely different stoichiometric air-to-fuel requirement. The stoichiometric air-to-fuel ratio varies between 10 to 6 (on volume basis) for fuels such as natural gas and biogas/landfill gas based on methane content in the gas. However, stoichiometric air-to-fuel ratio for producer gas is about 1.2 to 1.4 (on volume basis) based on the constituents of the gas.

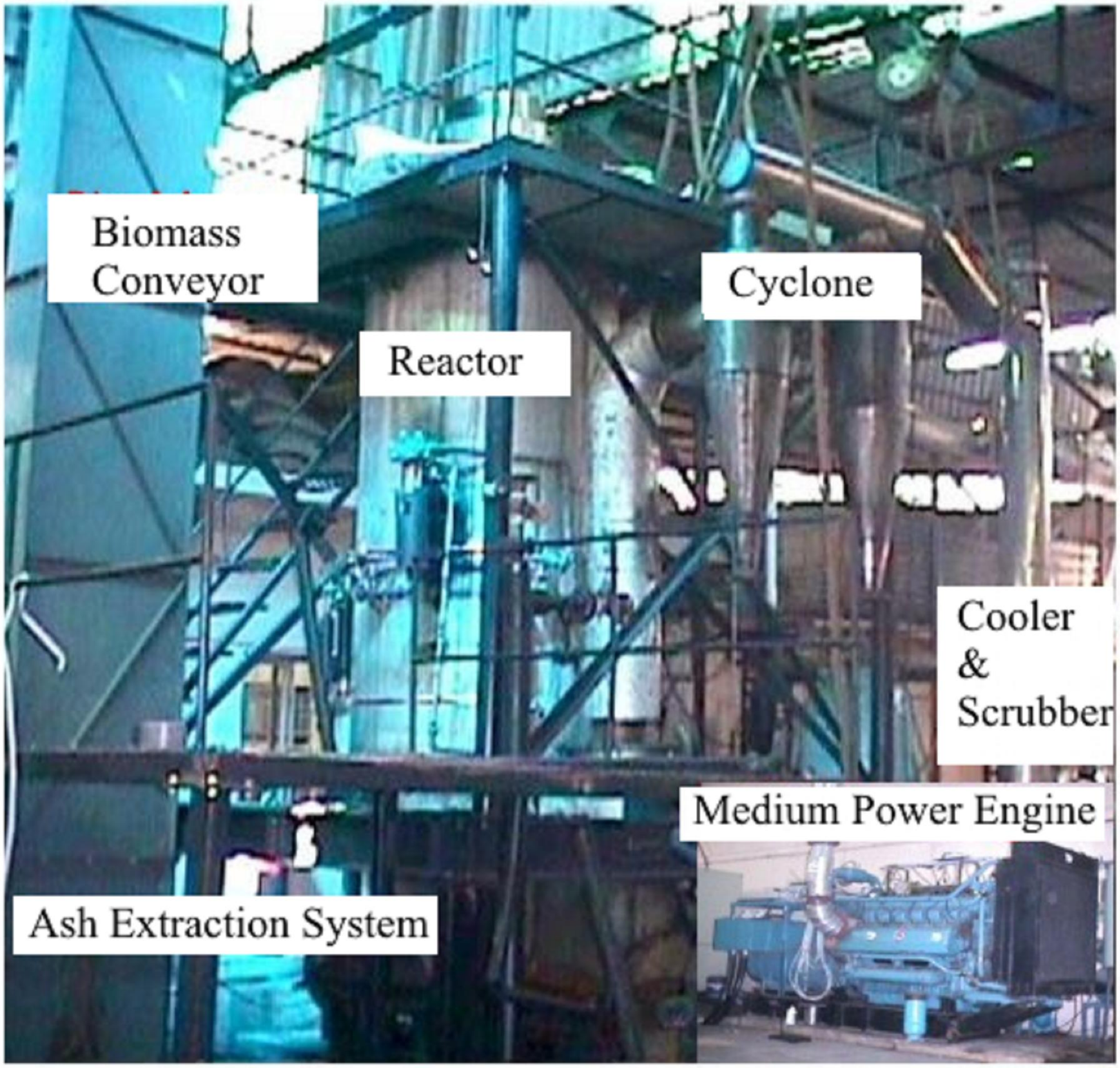


Plate 5.3: A View of a 250 kg/hr Open-Top, Re-Burn Down Draft Gasifier to Supply Gas to MPE. Major Sub-Systems of the Plant Identified. The Inset on the Right Shows the Gas Engine

Producer Gas Carburettor

The essential features in the gas carburettor are

- Ability to maintain the required air-to-fuel ratio (1.2 to 1.5) with load or throttle variation
- Smooth operation with minimum pressure loss
- Shut off the fuel in case of engine tripping or shut-down
- On-line provision for air/fuel tuning during testing

The above mentioned featured was incorporated in the development of gas carburettor and is shown in Fig 5.10. The carburettor is simple in design and does not have moving components. It has a separated port for air and fuel, where the individual ports could be modified or tuned to achieve the required air-to-fuel ratio. The carburettor is designed to operate in conjunction with the zero-pressure regulator. The combination of pressure regulator of gas carburettor was located between the gasifier and engine intake system as shown Fig.5.10. The zero pressure regulator ensures a gas pressure (downstream of the pressure regulator) identical to that of air pressure and this is achieved by connecting the air pressure line (downstream of air filter) to the upper chamber of the regulator. This arrangement ensures the regulator to maintain the gas pressure close to that of air pressure (~ a few mm below atmospheric pressure) and thereby the set air/fuel ratio irrespective of the total mixture flow rate.

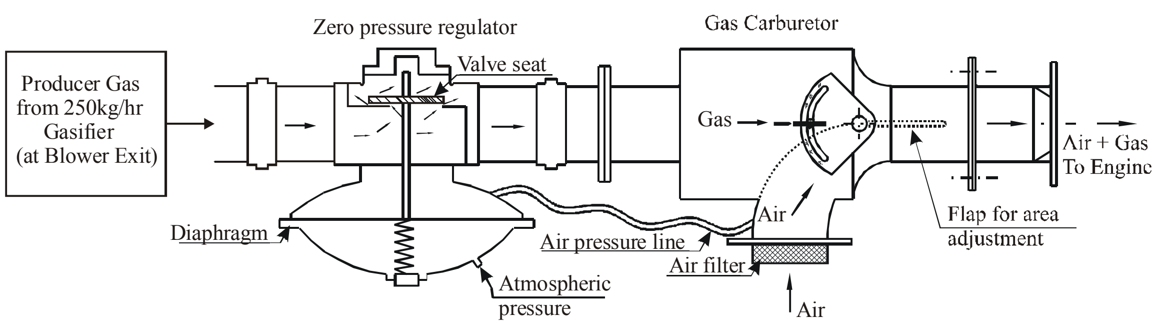


Fig 5.10: Schematic of Producer Gas Carburetor with Zero Pressure Regulator in the Gas-Air Line Circuit

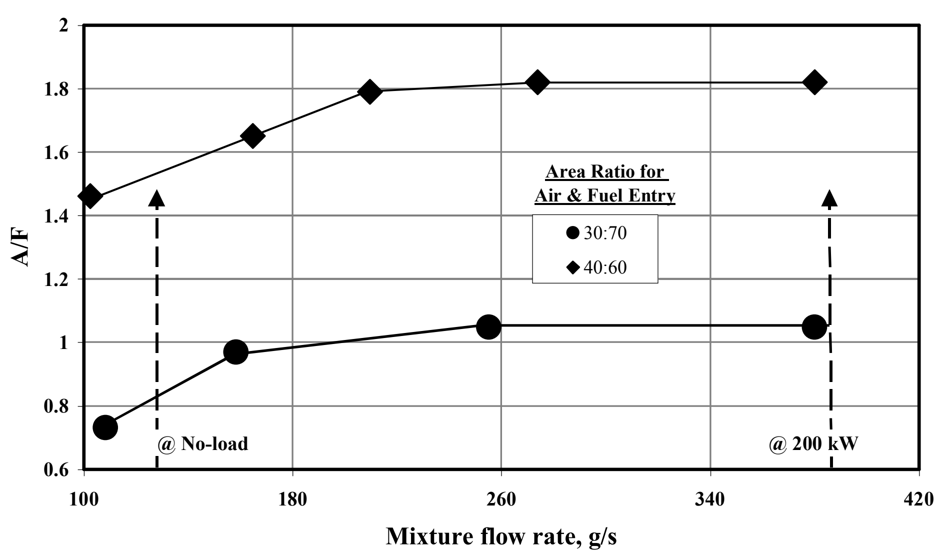


Fig. 5.11: Flow Tests with Gas Carburetor at Varying Area Ratio for Air and Fuel Entry

Flow tests performed with zero-pressure regulator and the gas carburettor reasonable functioning in terms of air-to-fuel ratio control against total or mixture flow rate variation as shown in Fig. 5.11. Flow test was conducted using a blower to stimulate the engine suction. The air and fuel flow rates were individually measured over a range of engines operating conditions. The two cases shown in the above figure correspond to the ratios for the air and fuel entry. These cases are possibly the extreme limits and are required operation point for the engine operation could lie in between them. The A/F ratio was reasonably constant beyond a specified mixture flow rates. This characteristic is desirable from the view point of engine operation – rich mixture for engine start-up and no-load operations, relatively linear mixture during part load operation. However, for peak load operation – stoichiometry or rich mixture is desired calling for the adjustment of the carburettor flap. Considering gas engine operation at the field level the carburettor is designed in a such a manner that in the event of load throw – affordable flap of the carburettor could move to full air flow (by motorizing) condition thus ensuring safety of the engine.

Experimental Procedure

The scheme of operation upto the exit of gas from the gasifier system around lines similar to that mentioned for SPE. However, instead of engine drawing the gas, the gas was drawn using a blower and made available for the engine operation. The gas was made available at higher pressure, typically 3000 to 5000 Pa, above the atmospheric pressure. The gas pressure had to be reduced for proper functioning of the gas carburettor and this was achieved using a pressure regulator placed with blower outlet and the entry to the carburettor. Relevant parameters as dealt in the SPE tests were measured and in addition, the turbocharger pressure was also recorded.

Experimental procedure as identified in Section I was adopted for preparation and subsequent evaluation of the engine. The engine was started directly using producer gas and load to stabilize for about 5 minute; subsequently the load was applied and gradually increased. Data relating to energy input in terms of gas flow rate and gas composition, power delivered and emission were recorded. Similarly, for combustion diagnostics, pressure-crank angle data was obtained in and around MBT.

Results and Observations

A trace of the gas composition and the calorific value is shown in Fig. 5.12. The gas composition in these experiments was found to be lower than obtained in the earlier instances. The LCV in these experiments is about 4.8 – 5.0 MJ/Nm^3 at the time maximum output from the engine. The reason this fact is brought out explicitly because the reduction in the mixture density has an implication on the maximum shaft output delivered and this is discussed subsequently.

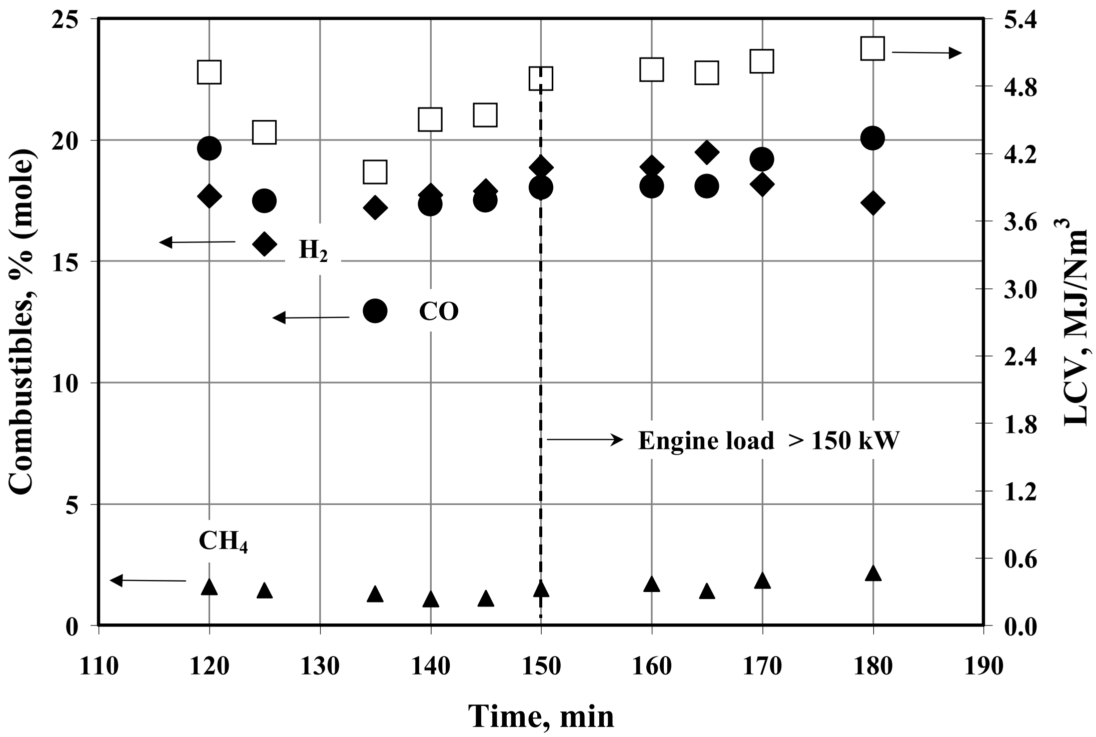


Fig 5.12: An on-Line Trace of Producer Gas Composition and LCV

The performance results presented below pertain to CR of 12 and at various ignition settings. A maximum gross brake output of 194 kW (including 12 kW consumed by the radiator fan) was recorded with an ignition advance between 12 and 14° CA at ϕ = 0.94. The value of ϕ was lower in the current case because of limitation coming from the gasification system. In fact, the gas composition in terms of combustibles deteriorated with increased supply of the gas to the engine. This therefore limited the input energy to the engine. The maximum net brake output of the engine at various ignition timings is shown in Table 5.10.

Table 5.10 Maximum Net Brake Power at Varying Ignition Timings

IGN, BTC	Φ	Net Elec. Power, kWe	Net Brake* Power, kW	Efficiency : Gas-to-Shaft, %
24	0.97	154	167	27.4
18	0.96	160	174	27.6
14	0.94	165	182	28.3
12	0.94	165	182	28.3

* Excluding Radiator Fan Power

The maximum net brake output was obtained at an ignition advance between 12 and 14° CA with gas-to-shaft efficiency being 28.3%. At relativity advanced ignition timing, the output was observed to reduce. The p-θ could not be acquired during this set of experiments; however, it was acquired in the subsequent tests at two ignition settings as shown in Fig. 5.13. The p-θ curve does not correspond to maximum output obtained at that particular setting in the earlier experiments. However, these correspond to a net brake output of 148 and 149 kW at 19 and 12° CA respectively, obtained under wide throttle open condition at θ = 0.91. The peak pressure and the point of occurrence at 19 and 12° CA are 65 bar, 7° ATC and 55 bar, 16° ATC respectively. Therefore, The MBT on this particular engine with producer gas should be between 12 and 14° CA. However, it is not clear as to why the brake outputs are almost identical when the ignition timings are vastly different. The point to be noted here the optimum timing; the maximum power output is obtained at slightly retarded ignition timing as compared to the SPE engine at comparable CR. This could probably be due to faster combustion due to higher turbulence (mean speed of the piston is 7.0 m/s against 5.8 m/s in SPE) and higher cylinder pressure and temperature due to turbo-charging.

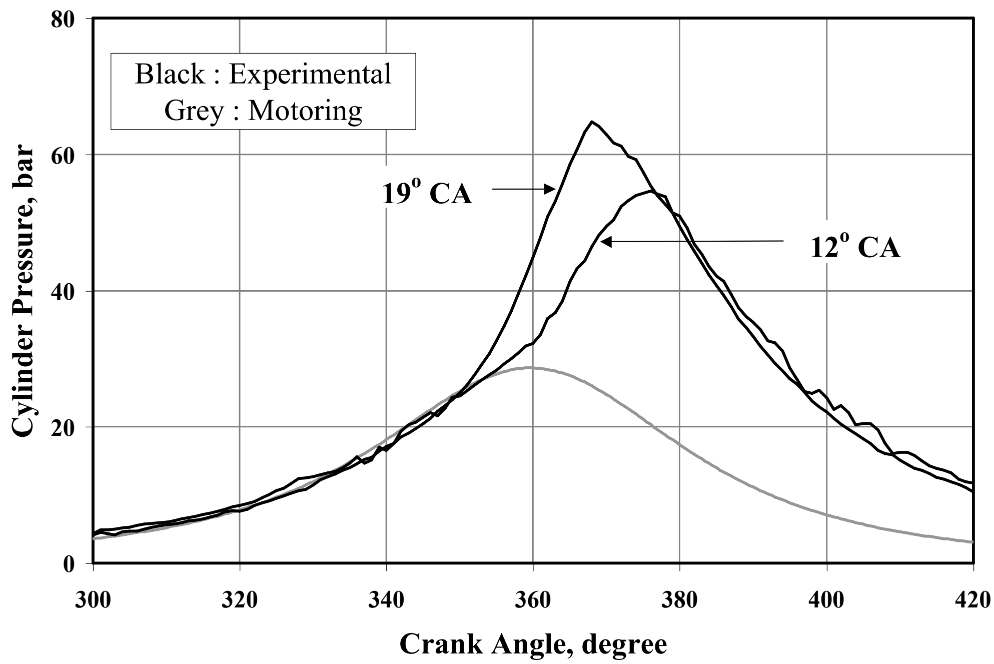


Fig. 5.13 p-θ Recording at Varying Ignition Advance. Ensemble- Averaged Data Over 30 Consecutive Cycles

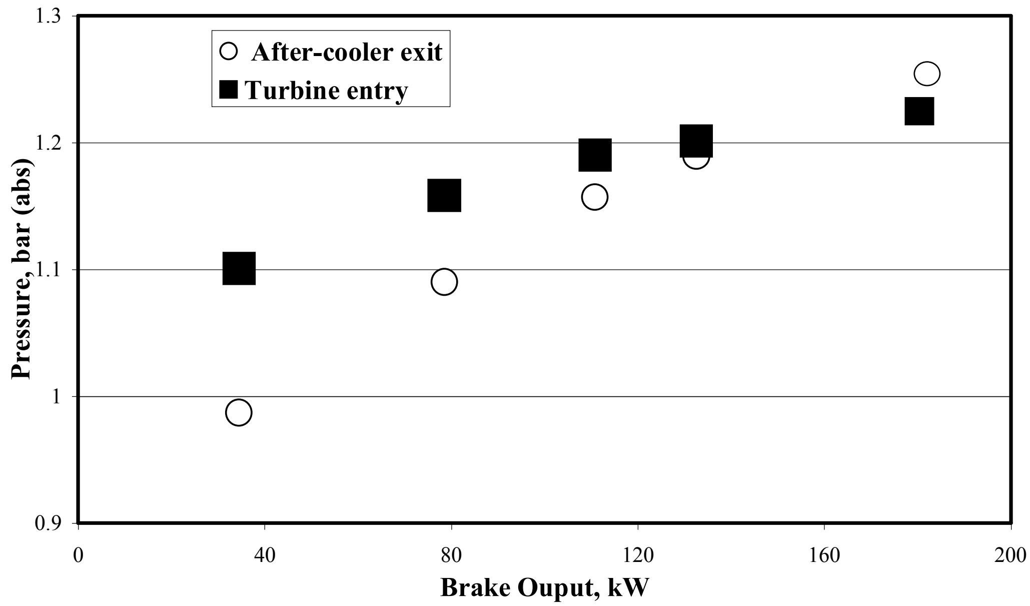
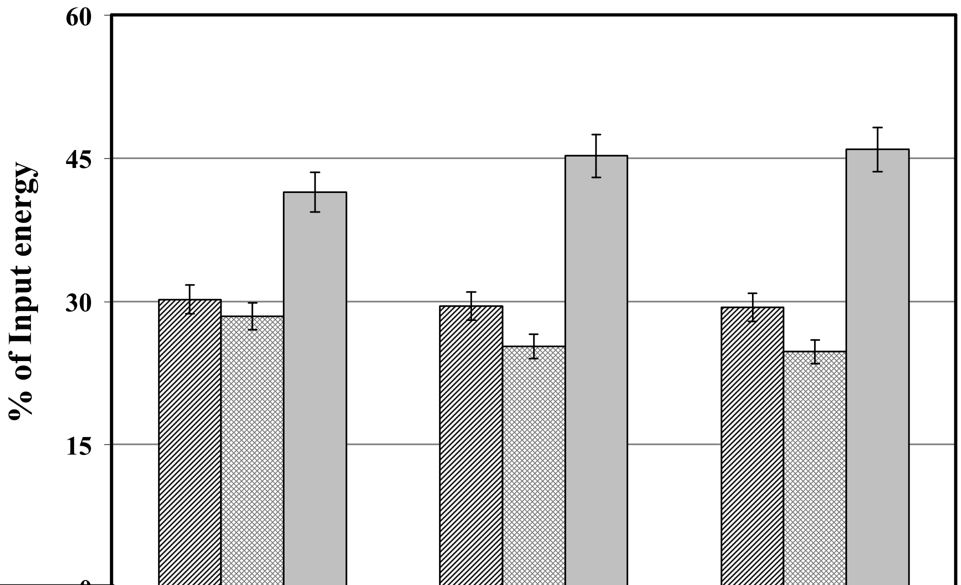


Fig. 5.14: Turbo-Charger Pressure at the Exit of After-Cooler and Turbine Entry.

The integrated p-θ data for the suction and exhaust processes, which is termed as pumping losses showed negative values in the range of -1 to -4 kW depending on the ignition advance, though positive values are normally expected for a turbo-charger engines. The reason for tubro supercharger incurring this pumping loss is evident from Fig. 5.14, which shows the variation of the turbo-charger pressure with brake output. The pressure into the inlet manifold i.e after-cooler exit is lower than the turbine entry pressure till a load of 140 kW. Even at this load the pumping losses will be negative because of the additional pressure loss occurring in the intake and exhaust valves. The intake manifold pressure becomes sufficiently higher than the turbine entry pressure at a load of 180-185 kW. This essentially means the engine incurred pumping losses till a large part of the load range (till about 60-70 % of the rated load – 290 kW) and gain in terms of positive pumping work could be expected only beyond 185 kW (when intake manifold pressure is higher than exhaust pressure). This, therefore, identifies the necessity for matching of the turbo-charger commensurate with the engine demand. This point is particularly relevant when operated with low energy density fuels with engine output is be rated to an extent of about 25% or more.

The overall energy balance at a different values of the ignition advance corresponding to peak output delivered is shown in Fig 5.15. The energy balance shows that at MBT about 30% was realised as gross break output (including fan power = 12kW), with the remaining 70% lost to exhaust and coolant. There is a re-distribution of energy pattern at advanced and retarded ignition settings, wherein the loss to the coolant increases with ignition advancement and similarly loss to the exhaust increases with delayed ignition. Further, the performance of the engine is represented in terms of normalized value of break specific fuel consumption (bsfc) in Fig 5.16. The bsfc at various ignition timing is normalized with bsfc at MBT with all values corresponding to full throttle condition. A change in two degrees in ignition timing appeared to have modest effect on the fuel consumption, however with 5 to 10 degree change; the impact was much more significant.



Ign., ° BTC	12	18	24
Brake output	30.2	29.5	29.4
Exhaust	28.4	25.3	24.7
Coolant & Miscl.	41.4	45.2	45.9

Fig. 5.15 Energy Balance at Varying Ignition Timing

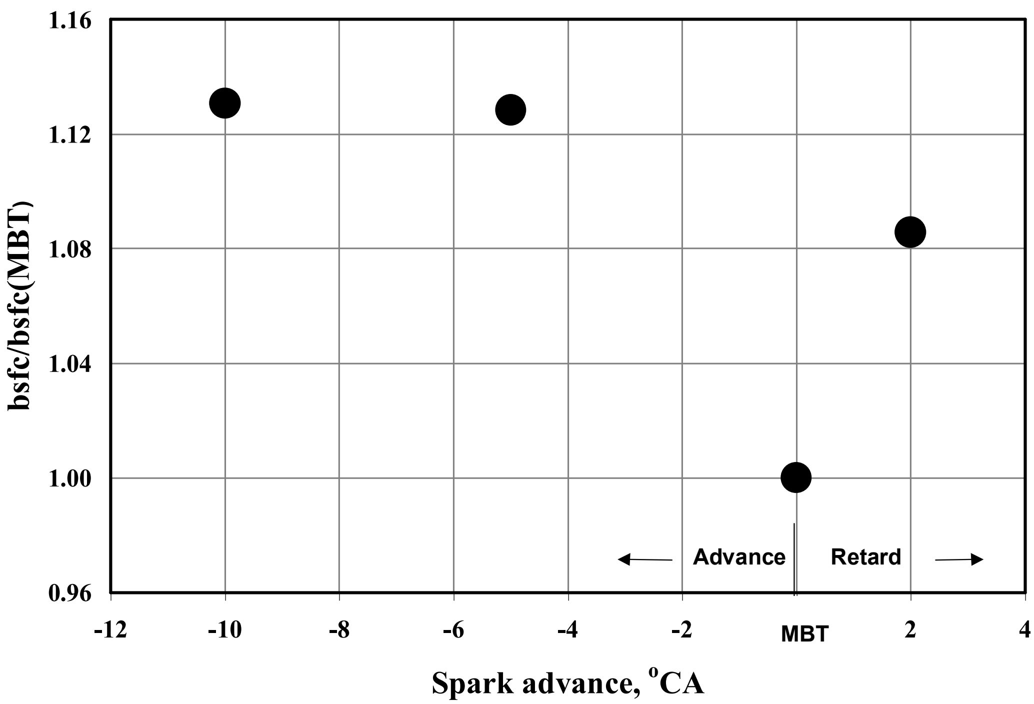


Fig. 5.16: Variation of bsfc with Ignition Advance. bsfc (MBT – 12° BTC) is 1.05 kg of Biomass or 2.8 kg of gas per kWhr

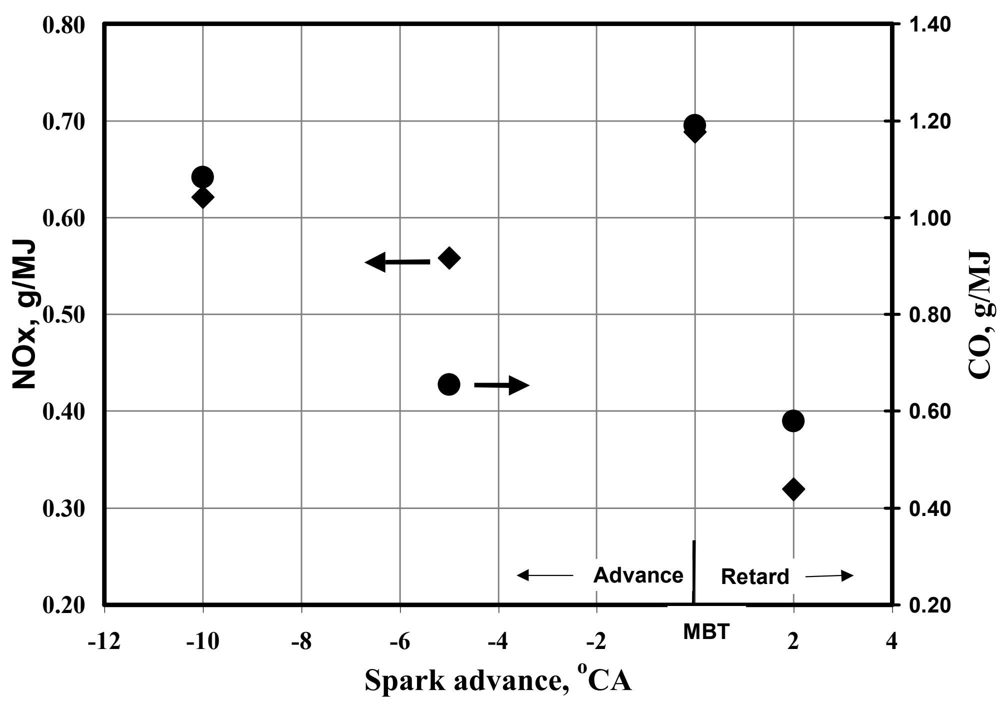


Fig. 5.17: MPE Emissions at Varying Ignition Setting Corresponding to Peak Output

The variation of emission in terms of NO and CO is shown in Fig 5.17 as function of ignition advance. There was a reduction in NO emission observed with retardation of ignition timing and this is attributed to reduction in residence time as in the earlier case. Similarly, there was also reduction in CO seen with retardation of the ignition setting implying completion of combustion even at MBT of 12° BTC.

Remarks

Like in the case of SPE, operation with producer is found be smooth with no indications of knock whatsoever from the p-θ curves. The engine and the gas carburettor system responded positively to the load changes. In addition, the carburettor was able to maintain the required air-to-fuel ratio with load changes. A gross brake output of 194 kW was obtained at an ignition advance of 12-14° CA, with ϕ = 0.94. This ignition advance is found to be consistent with the earlier results with SPE where A MBT of 15-17° CA was arrived at a CR of 11.5. The marginal retardation could probably be related with faster combustion because of higher turbulence (mean speed of piston is 7.0 m/s against 5.8 m/s SPE) and higher cylinder pressure and temperature due to turbo-charging. Table 5.11 the comparison of delivered power on MTE using producer gas and diluted natural gas. The data with diluted natural gas (biogas) has been recorded on a field system comprising of a Greaves Engine (Identical to MPE) at Ugar Sugar Works Limited, Belgaum, and Karnataka, India.

Table 5.11 Summary of MPE Results at MBT

Fuel gas	**Power (kW)* & Efficiency (%)**	**MBT, ° BTC**	**Mixture energy density, MJ/kg**	**Pressure- boost (turbo-charger)**
Diesel (Estimated)	290 – 310 kW *(Base-line data)*	-	-	1.5 –1.6
Diluted Natural gas (75% CH_4)	270 kW; 34%	28-30	2.48	1.5 - 1.6
PG	194 kW; 30 %	12 -14	1.90	1.47
PG (Estimated)	*214 kW (with 10% increase in LCV)*	*12 -14*	*2.10*	*Possibly > 1.47*

* Including Radiator Fan power

With the boost pressure of the order of 1.47 measured against an expected pressure of 1.52 to 1.6 in diesel, the de-rating of power with producer gas is about 32-37 %. This de-rating appears to be higher when compared to the results of SPE (26% at CR=11.5). However, as indicated earlier the mixture density in the experiments with MPE were about 4.8 to 5.0 MJ/Nm^3, which is about 10% lower than what has been measured on similar class gasifier. This also would shift the operations from the currently achieved lean (ϕ<1.0) towards richer limits. If an increment of 10% in the mixture density is considered the de-rating is reduced to 26-30% and compares closely with SPE results. The performance of producer gas against diluted natural gas (ϕ=0.97) fares slightly better with de-rating at 28%, and the de-rating further narrowing down to about 20% at the expected output of 214 kW with producer gas (LCV ~ 5.3 MJ/Nm^3).

2. CUMMINS Engine

Two gas engines have been adapted and tested with producer gas at the laboratory. The specifications of the two engines are as shown in Table 5.12 and 5.13.

Table 5.12 Medium Power level Engine Configuration Details

Parameter	**Specification**
Make and Model	Cummins India Ltd, G743G
Engine type	In-line, 6 cylinder, 4-stroke, naturally aspirated
Rated output – Natural Gas	100VA @ 50 Hz
Type of cooling	Water cooled with radiator
Bore x Stroke	130 x 134 mm
Swept volume/cylinder	1.78 Lt
Compression ratio	10:1
Combustion chamber	Flat cylinder head and a Shallow Bowl-in piston type
Ignition system - gas	Battery based distributor type with ignition advance/retard facility
Governor	Woodward Hydraulic
Spark plug & location - gas	Champion make, Central
Firing order	1-5-3-6-2-4
Alternator Efficiency	92%

Table 5.13 Medium Power level Engine Configuration Details

Parameter	Specification
Make and Model	Cummins India Ltd, GTA 855G
Engine type	In-line, 6 cylinder, 4-stroke, Turbocharged with after cooler
Rated output – Natural Gas	160 kVA @ 50 Hz
Type of cooling	Water cooled with cooling tower
Bore x Stroke	130 x 134 mm
Swept volume/cylinder	1.78 Lt
Compression ratio	8.5:1
Combustion chamber	Flat cylinder head and a Shallow Bowl-in piston type
Ignition system - gas	Battery based Altronic type with ignition advance/retard facility
Governor	Woodward Hydraulic
Spark plug & location - gas	Champion make, Central
Firing order	1-5-3-6-2-4
Alternator Efficiency	92%

The arrangement for testing was similar to that of the Greaves engine and all relevant parameters were recorded. These tests were conducted as a joint testing programme along with the Cummins India officials. The engine (G 743 G) engine was operated for about 75 hours, of which a 24 hours non-stop operation was contemplated. At the end of this operation, the engine intake components were examined for any deposits. The engine's intake components were clean with contaminant levels less than 30 ppb (parts per billion), which reiterated the fact that IISc gasifier system generates ultra clean gas. The output recorded on the two engines is shown in Table 5.14.

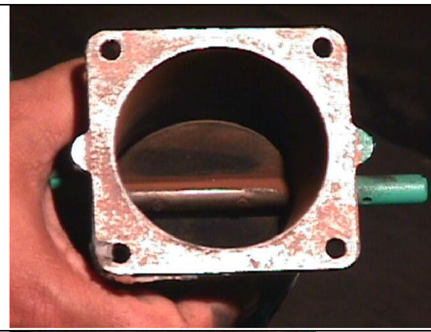
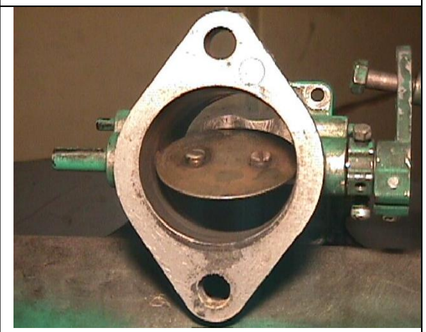
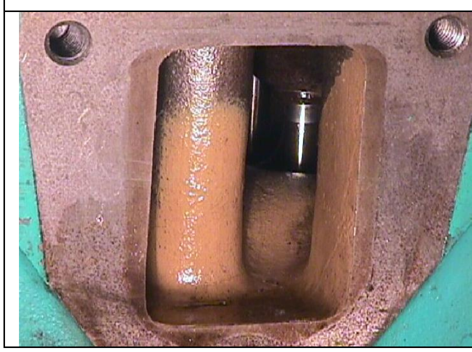
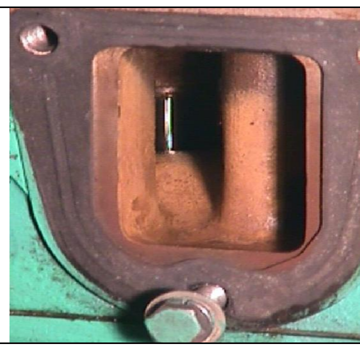
Gaseous Emissions from Engines

Table 5.14 Brake Power output on Cummins make engine

Model	IGN, BTC	Φ	Net Elec. Power, kWe	Net Brake* Power, kW	Efficiency : Gas-to-Shaft, %
G743G	24 -26	0.97	55	60	27.4
GTA855G	28-30	1.0	70+	77	27.0

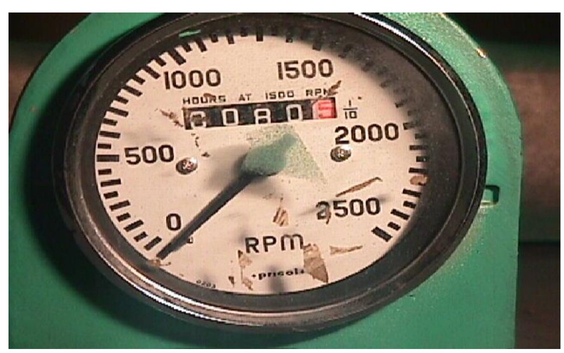
* Excluding Radiator Fan Power, + maximum power achieved with 75-kg/hr gasifier system

Plate 5.4 Butterfly Valve, Intake Manifold and Cylinder head

Initial	**After 6 Hours**	**After 24 Hours**
		
		
		

After 24 hours Test ……

Spark Plug



Hour meter

After 24 hours Test ……

Washing from Intake Manifold and Butterfly Valve

Gas Bubbler and Cellulose Filter

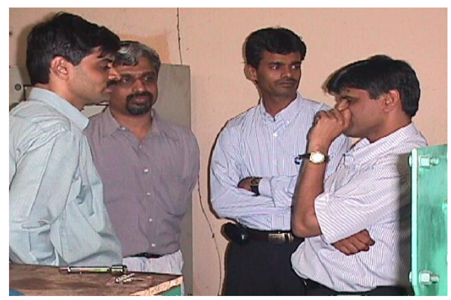


Plate 5.5 Cummins officials interacting with IISc Team during the 24-hr testing

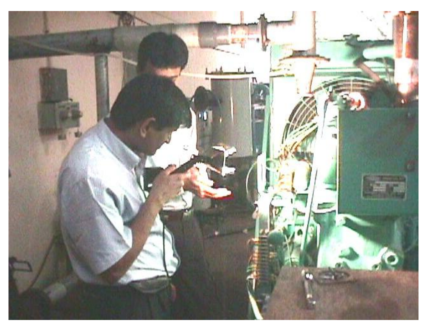


Plate 5.6 Cummins officials examining the gas engine after the 24-hr testing

Gaseous Emissions from Engines

Further, the emissions with producer gas operation are compared against existing emission standards of various countries in Table 5.15. The standard given for Indian conditions correspond to that of diesel powered vehicle (Euro 1) for gross vehicle weight > 3.5 tons [http://terin.org/urban/standard.htm.]. As stated earlier there are no standards existing for stationary engine (<2 MW), a suggestion made by Indian diesel engine manufacturers association [http://www/kirloskar.com/html/sw/emissions] is pending for approval with CPCB. These are in the brackets in Table 5.15 under India column.

The emissions with producer gas operation correspond to that measured under steady state conditions, using pre-calibrated instruments. However, the standards of various countries correspond to a specific procedure (steady state test cycle) meant for commercial engines. Therefore, the exact procedure might not have been followed in the current study, but measurements were made under steady-state conditions.

Table 5.15: Comparison of Emissions (g/MJ) with Producer Gas Operation against Existing Emission Norms in Various Countries

Parameter/Country*	USA	EU	Japan	India
CO	3.06	1.4 - 1.8	1.67	1.25 (3.9)
NOx	2.56	2.56	2.6 - 3.06	2.22 (5.0)
HC	0.36	0.36	0.4 - 0.56	0.3 (0.98)
PM	0.15	0.15 - 0.24	-	0.1 –0.2 (<3.5 Bosch)
SPE results between 6 to 20° CA for all CRs (min & max values) at Φ = 1.0 – 1.2				
Parameter/CR	17.0	14.5	13.5	11.5
CO	1.1 – 11.0	11.0 – 15.0	4.0 –16.0	9.0 –14.0
NOx	0.03 – 0.28	0.02 – 0.22	0.03 –0.20	0.05
PM	< 0.014			
MPE results between 12 to 24° CA for CR=12.0 at Φ = 0.94 - 0.97 (Greaves Engine)				
CO	0.58 – 1.2			
NOx	0.32 – 0.7			
PM	< 0.0005			

* Source: http://app10.internet.gov./scripts/nea/cms/htdocs/article.asp, PM is Particulate Matter

It can be seen that NO emission with producer gas is lower than all the existing norms. The CO results with MPE are encouraging; however there is large deviation with respect to SPE results. Therefore, treatment of exhaust in terms of CO is mandatory from the viewpoint if deriving maximum output (ϕ>1.0). This could be true even with respect HC emissions. However, Particular Matter (PM) is expected to be low even though measurements were not done because the input feed is gas with particulate matter less than 2 mg/Nm^3 (with MPE experiments), which amounts to < 0.5 mg/MJ. In the case of SPE experiments PM is estimated to the less than 14 mg/MJ with input gas containing particulate matter to the extent of 60 mg/Nm^3. The NO in diesel, dual-fuel and gas mode of operation is shown in fig 5.18.

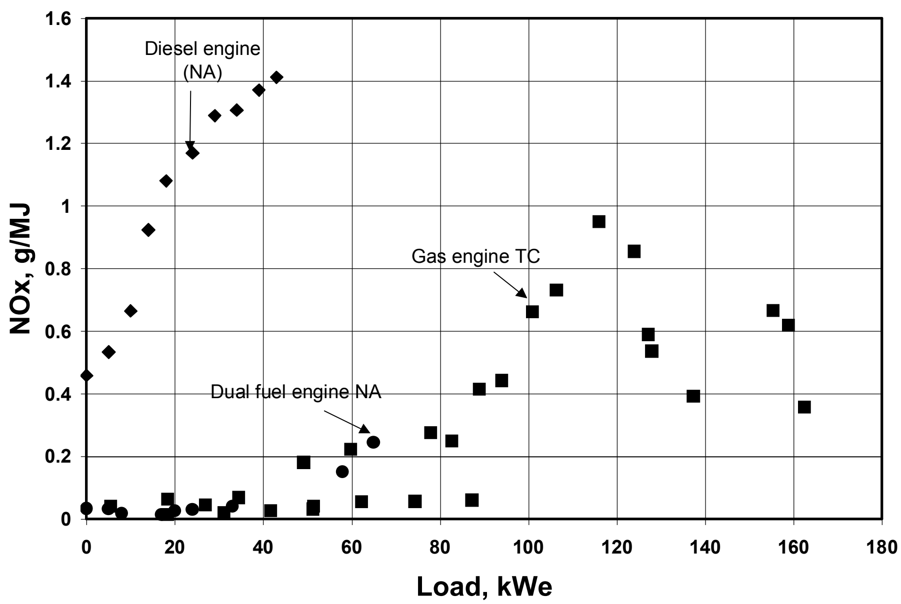


Fig. 5.18: NOx measurement on producer gas engine (a) variation with load (b) comparison against diesel and dual-fuel mode.

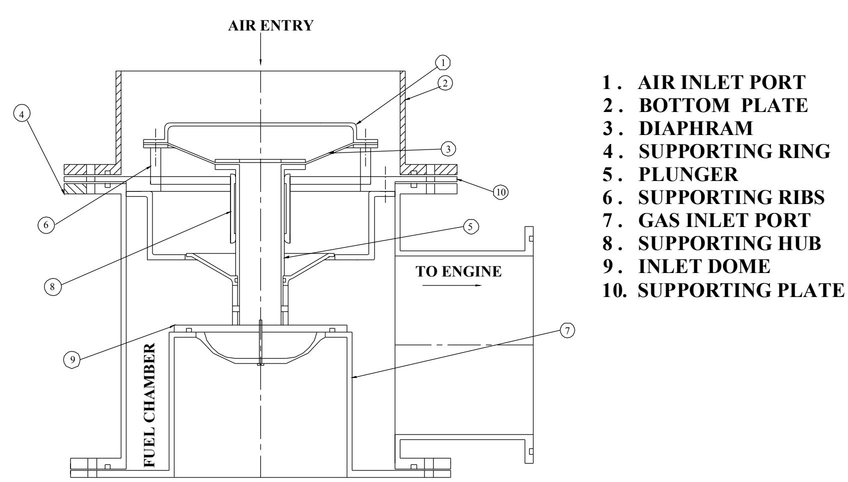
Package for gas engine operation

In the current scenario, there are no gas engines being commercially marketed by the engine manufacturers both in Indian and aboard. However, it is possible to adapt gas engines meant for other gaseous fuels like natural gas/bio – gas to operate on biomass derived producer gas. The calls for certain modifications in the fuel system and tuning of the ignition timings to suit operation on producer gas fuel. Some these requirements have been highlighted in the Chapter II – Medium Power Level Gas Engine. These requirements are stated again for clarity. The additional components for producer gas operation are

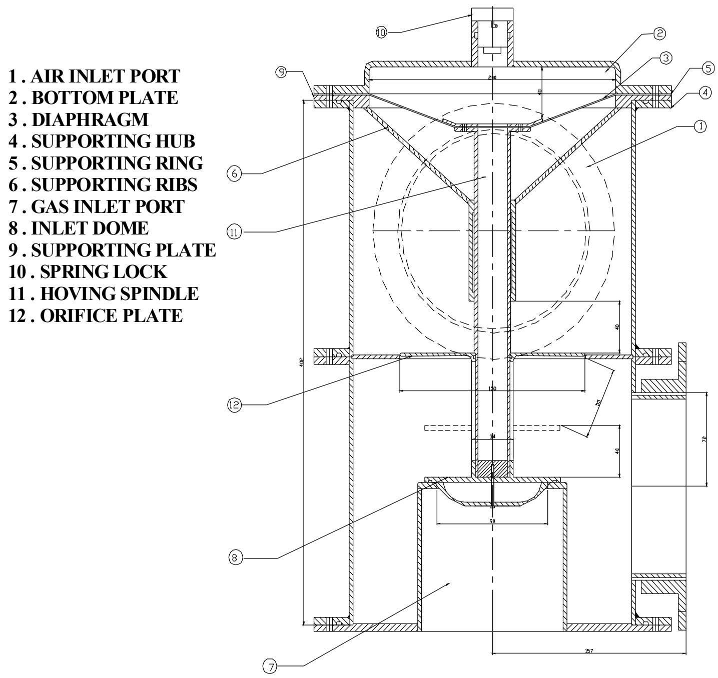
1. Producer Gas Carburettor
2. Zero Pressure Regulator

The operation of gas engine calls for a carburettor in order to maintain the required air/fuel ratio over the range of operating conditions. The required air/fuel ratio for producer gas is around 1.2:1 as against 6 to 10:1 for biogas/natural gas on volume basis. With no carburettors being available for producer gas and non-adaptability of biogas carburettor calls for indigenous development. As a part of this project, free versions of carburettor have been developed. The Version I is based on IMPCO carburettor, meant for biogas/landfill gas. Version I was based on theoretical considerations and dynamic tests on the engine gave sufficient indicators to improvise the system. During the trail runs with Version I (on Greaves gas engine), the carburettor performed satisfactorily upto a load of 70 kWe, beyond which there are starvation for air based on oxygen measurements in the exhaust. When additional provision was made to bleed air, the engine could take up higher loads. The amount of air bled into the engine had to be varied based on load variations and since tuning is not the correct way of operation, the same had to be incorporated in the new design. Moreover, in this version, the gas flowed over the plunger and resulted in deposition of water/contaminants in the gas, if any. The Version II included the improvement over the earlier design other than providing flexibility of making modifications in the hardware with minimal downtime. The schematic of Version I & II given in Fig. 5.19. The version III carburettor is has the following features.

- Ability to maintain the required air-to-fuel ratio (1.2 to 1.5:1) with load or throttle variation
- Smooth operation with minimal pressure loss
- Shut off the fuel in case of engine tripping or shut-down
- On-line provision for air/fuel tuning during testing



Version I



Version I

Fig. 5.19: Producer Gas Carburetor – Version I and II

The above mentioned feature was incorporated in the development of a gas carburettor and is shown in Fig. 5.20. The carburettor is simple in design and does not have moving components. It has a separate port for air and fuel, where individual ports could be modified or tuned to achieve the required air-to-fuel ratio. The carburettor is designed to operate in conjunction with zero-pressure regulator. The combination of pressure regulator and gas carburettor was located between the gasifier and the engine intake system as shown in fig. 5.10. the zero pressure regulator ensures gas pressure (downstream of the pressure regulator) identical to than of air pressure and this is achieved by connecting the air pressure line (downstream of the air filter)to the upper chamber of the regulator. This arrangement ensures the regulator to maintain the gas pressure close to that of air pressure (~ a few mm below atmospheric pressure) and thereby the set air-fuel ratio irrespective of the total mixture flow rate.

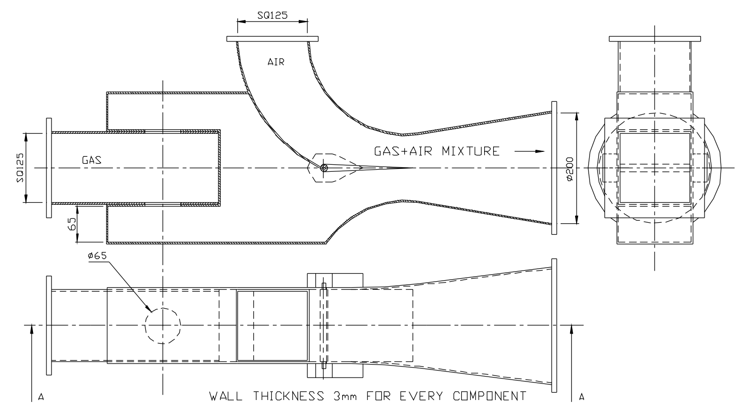


Fig 5.20: Schematic of Producer Gas Carburetor –version III

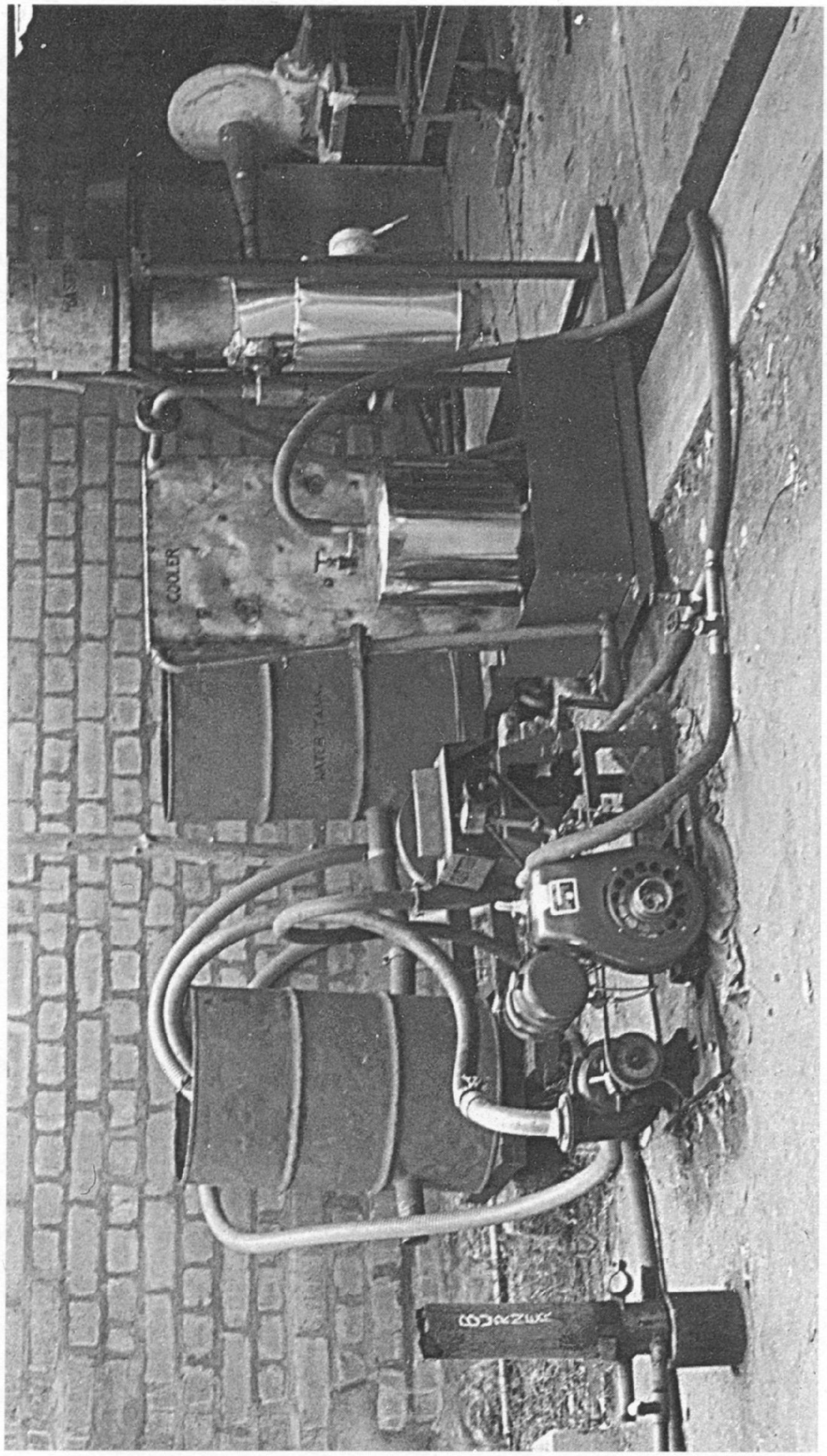
Apart from the above method of fuel-air regulation, the fuel regulation based on excess air factor in the exhaust (Lambda) for variable load operation has been found to be satisfactory. These are based on the series of tests conducted on the Greaves gas engine along with the producer gas carburettor (without zero pressure regulator) upto a certain capacity. However, keeping in view the ruggedness and robustness required for field level operations, the commercially available pressure regulator along with the in-house designed gas carburettor is the preferred till the point of time of occurrence of long duration trials with the Lambda based unit. At the point, the Lambda based unit could be based with on fuel or air regulation in order to achieve the required conditions for satisfactory variable load operation.

Coming to the operations on producer gas, the ignition timing needs to be tuned for optimum performance. The optimum ignition timing is a strong function of the fuel gas composition and the engine characteristics like the combustion chamber designed and engine operational speed. Nevertheless, a short range of numbers have been identified as shown in the Table 5.16, which are based on the series on development work carried on engines of various make at varying compression ratio. However, these data can be used as initial indicators and further tuned for best performance based on actual engine configuration and fuel gas composition.

Table 5.16 Optimum Ignition Timing*

CR	**Ign Timing, BTC**
17	6-10
14 -15	10-12
12 -13	12 -14
11 -12	15- 17
10-11	22 -24
8 -9	26 -28

*for a gas composition of: 18-20% each of H_2 and CO, and 2% CH_4


COOLER
WATER TANK

6

Special Applications

Two applications are identified here as test cases for use of producer gas.

Aluminium industries

Generally, aluminium industries use petroleum-based fuels like HSD, LDO, and furnace oil for their thermal needs. The price and availability of these fuels are dictated by international norms and have become so large that the cost of energy in the aluminium melting industry is a significant part of the final product cost (~30%). Consequently, a system using the gasification system as well as a furnace was designed and built to burn the producer gas in the furnace to achieve the desired temperature.

The furnace used was a standard Aluminium melting furnace with a top door. Dual fuel Wessmann burner with accessories such as diesel pumping unit, air blower and other control valves were mounted on the furnace. Noting that the existing systems built several decades ago did not have a recuperator, and that significant benefit could be obtained by adding one, a recuperator was designed and included in the circuit in the exhaust line to preheat the combustion air.

Aluminium melting experiments were conducted to determine the initial heat rate, melt rate as well as the steady melt rate. Since industries usually work round-the-clock, the steady melt rate was an adequate parameter for comparison. The comparison is shown below in the Table 6.1 as well in Plate 6.1.

Table 6.1 Operation details using PG

Item	Diesel	PG without RC	PG with RC
Fuel consumption rate	6 l/hr	24 kg/hr	19 kg/hr
Time for initial melt	4 hours	4 hours	2.5 hours

[PG = Producer gas; RC = Recuperated]

[Calorific value of 1 litre of diesel is 36 MJ; Calorific value of the gas produced by 1 hg biomass (that produces 2.5 kg of gas with a calorific value of 4.6 MJ/kg) is 11.5 MJ.
To replace one litre of diesel, biomass required = 36/11.5 = 3.2 kg]

Plate 6.1 : The above photograph has a recuperator shown just below the top cone-like exhaust tubing. The air is forced from the blower through the recuperator and taken to the burner section of the furnace

Notes: The normal combustion system without recuperator for producer gas is able to match the result for operation with diesel without the recuperator. When recuperator is used, the heating rate is substantially raised even if the gasifier power is brought down from 24 kg/hr to 19 kg/hr. It can also enhance the temperature to values in excess of 1000 °C. In fact, temperatures had to be limited to 1200 °C to ensure the integrity of the furnace.

Iron ore reduction

An application involving metallurgy was brought to the attention of the team by an industrial group in Hyderabad. M/s Hytech Blue Metal Powder Alloys (P) Ltd., in association with International Advanced Research Institute (ARCI) had developed a new process for direct reduction of blue dust iron ore to metallurgical grade iron powder with low carbon. The sponge iron powders, until now, have been made only by M/s.Hoganaes of Sweden.

This product has been claimed to have a large application areas in friction, anti-friction grade applications like sintered brake pads, brake discs, anti-friction bearing in critical areas. This material is also non-corrosive in nature and has other wide application such as medicinal value for fortification of iron as Sulphate with high purity. In the U.S.A, about 500 tons of this powder is used in bread production for iron fortification. Further processing of this powder has utility in specialty electrodes production, stainless steel castings, permanent cast magnets, etc. Production of fine particle size powders has application in thermal batteries and thermal pads as pyrogenic powders. It could also be applied in mechanical alloying powder production. The only constraint to withstand global competition is economics of production. The cost of fuel in heating is the major constituent in containing viability. While fossil fuels like LPG/CNG were contemplated, the cost and availability of these fuels in any place seems to be the constraint factor in the use of this technology.

A 100kg/hr biomass gasification system was supplied for field experiments. The process duration was 36 hours and two experiments were conducted. With the improvements made on the gasification system after learning from the first test, the second test was declared successful with peak temperatures achieved being 1200 ^{0}C and the iron content in the material had increased to 98.5%, considered somewhat unique to the process. Larger industrial projects are being based on this idea.

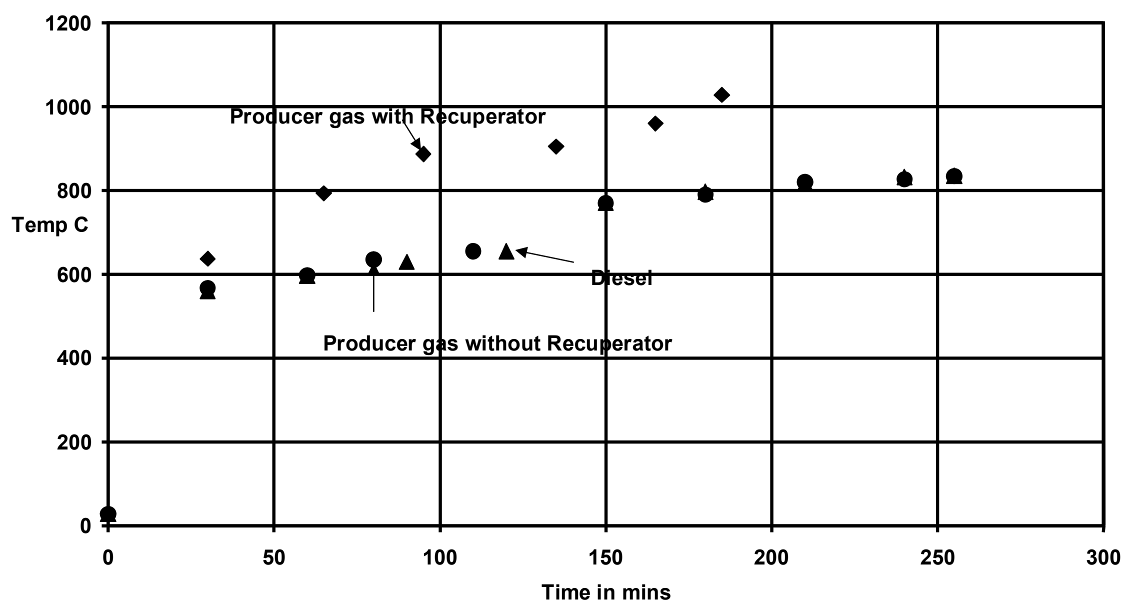


Fig.6.2 Comparison of Furnace Temperature in Diesel and Producer Gas (with and without recuperator)

Value added products from biomass-to-electricity plants

Activated Charcoal from gasifiers

Charcoal results from the loss of volatiles from biomass. Gas phase combustion occurs during the first phase when volatiles are generated. During the second phase, char conversion takes place in a reactor with the gases resulting from partial combustion – namely, H_2O and CO_2 — resulting in additional contribution to producer gas composition. One classical approach to activating the charcoal is to react it with water vapour at high temperatures (800 to 1000 ^{0}C). In the reactor meant for a gasifier, the char itself moves through the system with non-isothermal distribution of temperatures in a gaseous atmosphere where both water vapour and carbon dioxide are present and the residence time is controlled by the power at which the reactor is operating. Even though the conditions under which the char undergoes reaction with H_2O and CO_2 are not the best required for activation of a predetermined quality, it should be noted that conditions favourable for activation are present. Thus, one can expect activated charcoal as the residue from the reactor. The char can be extracted from the reactor either through a grate in which case, the char will drop into water of the water seal or a screw extractor. In the former case, the char will absorb some chemicals present in the water and in the latter case, one has dry material. Typical specifications for activated charcoal are as follows.

Solvent Recovery

Table 6.2 Typical Properties of Solvent Recovery Activated Carbons

Type	Granular Carbon	
Designation	HS3	HS18
Granulometry (mm)	1.7 – 3.35	1.7 – 3.35
CTC (%)	60	65

Table 6.3 Potable Water Treatment

Typical Properties of Water Treatment Activated Carbons		
Type	Granular Carbon	Powder Carbon
Designation	HS3	HS15
Granulometry (mm)	0.6 – 1.4, 0.6 – 2.36	<0.075
Iodine Number (mg/g)	1100	800
CTC (%)	55	40

Table 6.4 Ground Water / Air Purification

Typical Properties of Ground Water/ Air Treatment Activated Carbons		
Type	Granular Carbon	
Designation	HS3	HS9
Granulometry (mm) (Ground Water)	0.6 – 2.36	0.6 – 2.36
Granulometry (mm) (Air Purification)	2.36 – 4.75, 1.7 – 3.35, 3.35 – 6.3	1.7 – 3.35
CTC (%)	55	30

A survey was conducted of the specifications quoted by several manufacturers on the typical properties of Activated Carbon in the market. Based on the responses from a select few, the following representative data has been put together.

Table 6.5 Properties of Powdered Activated carbon specified by manufacturers

Methylene blue value (mg/g)	280	250	200	235
Iodine value (mg/g)	1100	960	750	600

(Properties are for unwashed powdered variety)

Suggested applications: Decolourisation of edible and inedible oil; Effluent treatment; Dye intermediates, Decolourisation of fine and bulk drugs.

Table 6.6 Properties of Granulated activated carbon specified by manufacturers

Grade	VVD – 500	VVD – 650	VVD – 800	VVD – 900
Iodine No.(mg/g)	500 to 600	650 to 750	800 to 900	900 to 1000.

Applications: Deoiling of condensates; Dechlorination of water; Removal of pesticides from water.

As can be noted from the tables, there are variations in the manner in which the specifications are presented. The specifications contain the values of Iodine number, Methylene Blue number, Carbon tetrachloride (CTC) number, and some times, Butane value. Some of these parameters have gone out of vogue because of the chemical toxicity involved in their use in the tests. Iodine number is measured according to the procedure laid down in ASTM Standard D4607 – 94.

Manufacturers of activated carbon quote values for only one or some of these parameters and in some cases, different set of parameters for the same application. While all the parameters are related to internal surface area, it is possible that different ways of making the activated carbon can produce different distribution of the pores and this can account for differences in the correlation between different parameters. To examine the possible relations, experiments were carried out with the char (from coconut shell char) samples from the same lot in different ways. The results are shown below. There is correlation between the different numbers though there is no simple relationship.

Table 6.7

Condition of coconut char sample.	**Iodine No. (mg/g)**	**Butane activity, (%)**
From gasifier (before further activation)	365	8.1
Further activation with combustion products (for 45 min)	533	10.7
Heating in absence of air (60 min)	645	13.8
Steam activation (60 min at 800 – 850 °C)	729	17.6
Steam activation (120 min at 800 – 850°C.)	872	18.8

Attempts were made to characterize the char extracted from the reactor mostly under wet conditions for the Iodine number and throughput. These data are presented below.

Table 6.8

Source	**Iodine No.**
IISc. 250 kg/hr gasifier	480 – 550 (@5% extraction) 600 – 650 (@4% extraction)
Senapathy Whiteley	500 – 520 (@ 4 – 5% extraction)
Synthite, Coimbatore	430 to 500 (@ 4% extraction)
Sample with high temperature treatment	780 – 850 (60- 70 mins, 850 - 950°C)

It was interesting to note that the iodine number of the samples was as large as 650 on occasions. There were also samples that had iodine number of 430. This variability was inferred to be due to the samples having taken up some chemicals from the water in the water seal. Hence, it was thought that a simple regeneration procedure needs to be adopted. This was done by wetting the sample obtained and heating the samples to round 850 - 950 ^{0}C which is necessary for obtained required activation, for about an hour. The duration was decided by noting that there were combustible volatile issues from the system until about an hour. Allowing for little extra time helped in ensuring that all the pores are cleared from the presence of chemicals. Material obtained from one of the field installations was classified as required by granulometry considerations, processed by the indirect heating technique as described here and analysed. This showed that the Iodine number was about 780 to 850 and Methylene Blue number about 50 to 55 and Butane value of 16 to 18.

Results of activation of the carbon obtained from gasifier

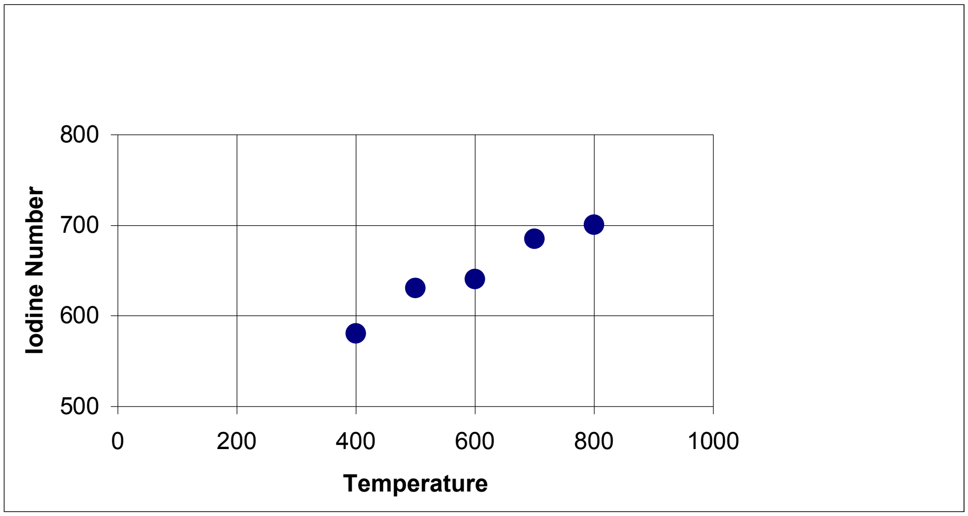


Fig 6.3 Iodine Number vs Temperature (Coconut char sample) Reaction Time: 15 minutes

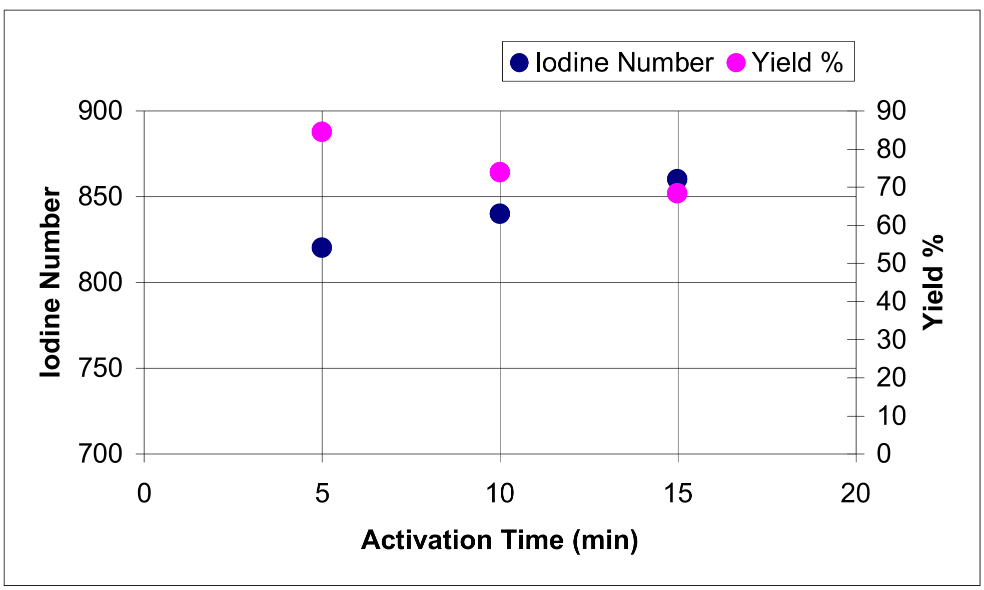


Fig: 6.4 Iodine Number vs Time & Yield % (Eucalyptus Char sample) Reaction Temperature: 850° C

Generation of precipitated Silica from rice husk char / ash

Rice husk char contains carbon and silica as well as some other inorganic oxides interspersed in the structure. In comparison to woody biomass, char conversion times are inordinately long due to the carbon being found between the Silica molecules in a manner that carbon is difficult to access. Typically, in a combustion process, rice husk loses 60% volatiles and 10% carbon. The remaining 10% carbon and 20% ash will remain. This material can be processed to separate the Silica from the ash leaving behind carbon with some inorganics. The Silica is amorphous as judged by X-ray crystallography and has a very high surface area. Its properties are the tap density (between 100 to 250 kg/m^3) and surface area (130 to 200 m^2/g).

They find uses in a variety of applications. (a) Reinforcement of rubbers and plastics, (b) Thickening and thixotropy of coatings and paints, printing inks, plastic and cosmetics, (c) Matting of lacquers, coating, paints and plastics, (d) Anti-blocking of plastic foils, (e) Free running and free flow of sticky solid or liquid substances, (f) Carrier for pesticides, catalysts, (g) High temperature insulation, (h) Stabilising (eg of beer, silicon rubbers), (i) Desiccants, and (j) Non eutrophic water softening (eg “builder” materials in washing).

Synthetic amorphous silica is produced in four different forms for the industrial applications. (a) Fumed Silica (Aerosil, pyrogenic) – they are produced by vapour phase processes like hydrolysis of silicon tetrachloride or high temperature oxidation and hydrolysis of silicon compounds such as silicate esters, (b) Colloidal Silica – It is a stable dispersion of amorphous silica particles in water (3-10 mm particle size) having specific surface of 50-270 m^2/gm with silica content in the range of 15-50 percent by weight, (c) Silica Gel – It contains three dimensional network or aggregated silica particles of colloidal dimension. The pores are filled with water. It is generally prepared in acidic conditions and (d) Precipitated silica – They are prepared by destabilisation of sodium silicate molecules under conditions that avoid the formation of continuous gel structure. Precipitated silica is powders obtained by coagulation of particles from aqueous solution under the influence of appropriate electrolyte concentration.

Table 6.9 Product Characteristics and Description

Appearance	Precipitated Silica is a white free flowing powder.
Chemical Formula	**SiO_2**
Molecular weight	60.00
Specific gravity	2.1 to 2.3
Ultimate particle size, mm	0.0126
Ph	6 to 8.0
Density bulk gm/cc	0.10 – 0.18
Solubility	Insoluble in water or acids except hydrofluoric acid Soluble in alkali

Worldwide Consumption and Application of Precipitated Silica

The consumption of precipitated Silica worldwide is around 6,75,000 M.T/annum (1994) and the typical consumption pattern is as follows:

Shoe soles = 40%; Tyre = 16%; Carriers (for the flow) = 16%; Tooth Paste = 9%; Paper & Paints = 8%; Technical Rubber Products = 5%; Others (plastics, zeolite, lead Acid batteries, inks, dentifrice, Animal feed stock, membranes etc, brake lining) 6%

Precipitated Silica from Rice Husk Ash

IPSIT (Indian Institute of Science Precipitated Silica Technology)

Process:

The silica precipitation technology developed at CGPL, Indian Institute of Science, Bangalore is a novel method for silica precipitation where the chemicals used are regenerated making it a closed loop operation. Successful studies for extraction of silica on laboratory scale which meet the industrial requirements have been carried out. Also studies are being carried out for suitable application of the undigested ash obtained after extraction, in water treatment plants with or without further improving the activated carbon content of the ash. 70 % conversion is achieved on ash basis and around 90 – 95 % on silica in ash basis.

The following gives the brief description of the process.

Digestion

This involves the digestion of the rice husk ash with caustic at specific conditions. In this process the silica in the ash is gets extracted with caustic to form sodium silicate solution. After the completion of the digestion the solution is filtered for the residual undigested ash present in the solution. The clear filtrate is taken for precipitation.

$$2NaOH + Ash \xrightarrow{Energy} Na_2O.X\,SiO_2 + H_2O$$

Precipitation

This step involves precipitation of silica from the sodium silicate solution. Carbon dioxide at a specific flow rate is passed through the silicate solution at design conditions. Continuous stirring is employed during the operation. The precipitated silica is filtered, washed with water to remove the soluble salts and dried. The filtrate containing sodium carbonate is taken for regeneration.

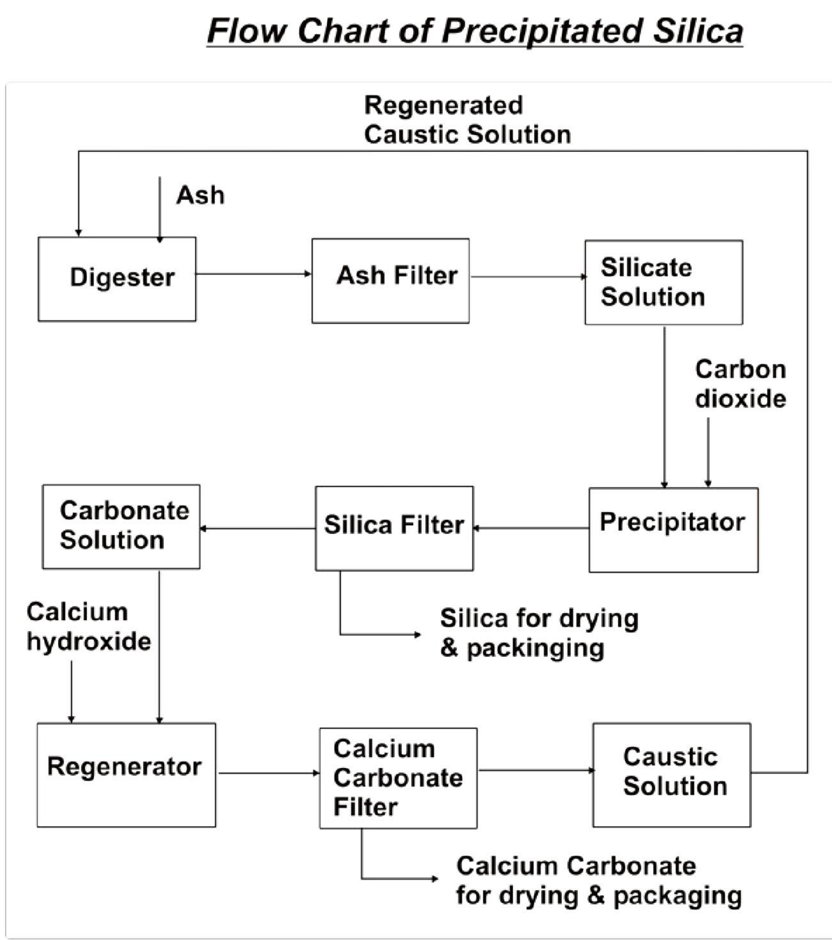
$$Na_2O.\ X\,SiO_2 + CO_2 \xrightarrow{Energy} Na_2CO_3 + X.SiO_2$$

Regeneration

Regeneration is the step where calcium compound reacts with the sodium carbonate to form calcium carbonate and sodium hydroxide. The resulting solution is filtered to remove the solid calcium carbonate and the aqueous sodium hydroxide is used for digestion again. The calcium carbonate is washed with water and dried. The dried calcium carbonate can be either calcined to get calcium oxide, which is reused, for regeneration or the calcium carbonate is sold and fresh calcium hydroxide is used for regeneration which gives an option of one more value addition.

$$Na_2CO_3 + Ca(OH)_2 \xrightarrow{\text{Energy}} 2NaOH + CaCO_3$$

Block Diagram:



Flow Chart of Precipitated Silica Process

Features

1. NaOH is regenerated upto 90 %.
2. Calcium carbonate is treated as a by product here.
3. No regeneration of calcium carbonate is attempted here.

Typical Properties of Silica Precipitated at CGPL:

1. Nature:	Amorphous powder
2. Appearance:	White fluffy powder
3. Purity:	$\geq$ 98 %
4. Surface Area:	150 - 200 m^2/gm
5. Bulk density:	120 – 200 g/liter
6. Loss on Ignition:	3.0 – 6.0 %
7. pH of 5 % slurry:	6.3 $\pm$ 0.5
8. Heat loss:	4.0 – 7.0 %

Plate 6.2 Precipitated Silica Obtained by *IPSIT* Process

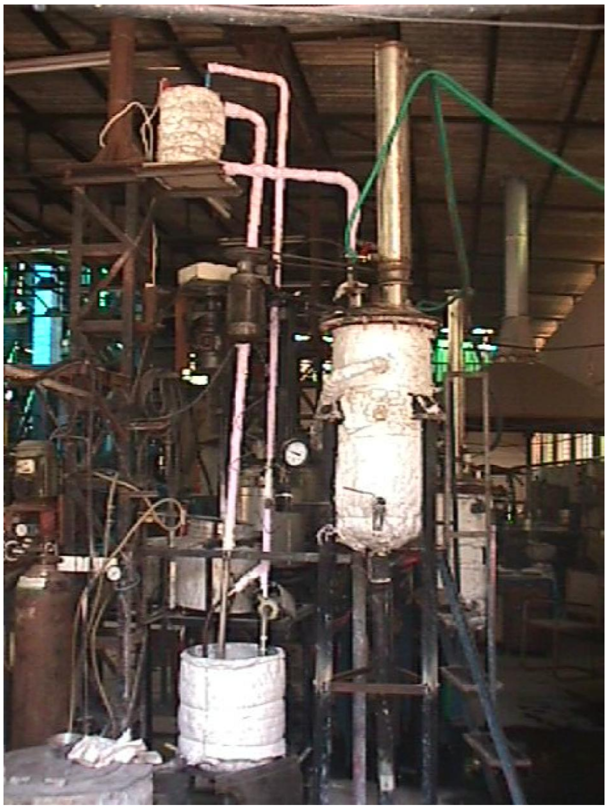


Plate 6.3 Precipitator used for Silica Production

Plate 6.4 Digester for ash silica extraction from ash

7

The National Biomass Resource Assessment Program

This activity was taken up at CGPL at the behest of MNES. MNES had launched a major program in which about 500 taluks in India were to be covered by surveys to reveal the excess bio residues for power generation. IISc got involved at the end of a phase when fifty studies had been made and the entire documentation was in the form of individual reports. In the initial stage, the idea was to appreciate what has been done in the studies and obtain an integrated picture. This effort got enhanced into a major effort in which the national bio -residue atlas was to be created from (a) agricultural output from reliable sources like the Ministry of Agriculture, Government of India, (b) agro-industrial residues from state data sources, (c) plantation residues from local data sources, and coupled with the utilization of the bio-residues for (i) fodder, (ii) domestic cooking, roofing (for thatched roofs), etc and (iii) other semi-industrial uses. It was also conceived that the actual location of the bio-residue or at least biomass production area be made available on a map to the users. The users could be several – investors and industrialists who wish to know where to look for the bio-residues and what would be available in a given area.

In executing this project, IISc receives support from a partner in this project - Regional Remote Sensing Service Center (RRSSC) of Indian Space Research Organization who provides GIS based maps for the identification of cropped areas all across the country. Additional work related to crop identification is being done using the data on NDVI (Normalized Differential Vegetation Index). Some of these are at the level of new knowledge and hence what is guaranteed from the maps would be the cropped area with a probability index attached to the specific crop identified. The crop map for Belgaum district of Karnataka state with relevant legend is shown on the next page which was generated at CGPL, IISc.

Table 7.1 indicates the agricultural scene over all the States in India. Table 7.2 shows it for one of the states presented here as an example. Table 7.3 shows the sample for a district containing details of various crop residues, the amount used for societal purposes and the excess available in each district. Tables 7.4 to 7.7 show the details for crops, namely, corncobs and coconut shell and fronds and cotton stock that can be used profitably for gasification purposes all across the country. All the tables are based on the data for 1998-1999. It must be recognized that due to the agricultural production depending on rainfall, there are regional variations that will affect the data in later years. Hence, these data can be used as preliminary inputs for a project design.

Spatial Distribution of Crops for Belgaum

Crop	Satellite kHa 1999-00	DES Karnataka kHa 1999-00	MOA kHa 1998-99
Jowar	196	195	193
Sugarcane	138	140	----
Maize	112	117	109
GroundNut	90	89	86
Paddy	65	63	63
Wheat	57	54	54
Cotton	52	49	66
Bajra	42	40	31
Other Crop	71	55	182
Uncovered	184	150	----
Total	1007	952	784
Total Geographical Area kHa			1337

The data has been integrated by CGPL, IISc using GIS inputs from RRSSC and the statistical data provided by the Ministry of Agriculture, GOI.

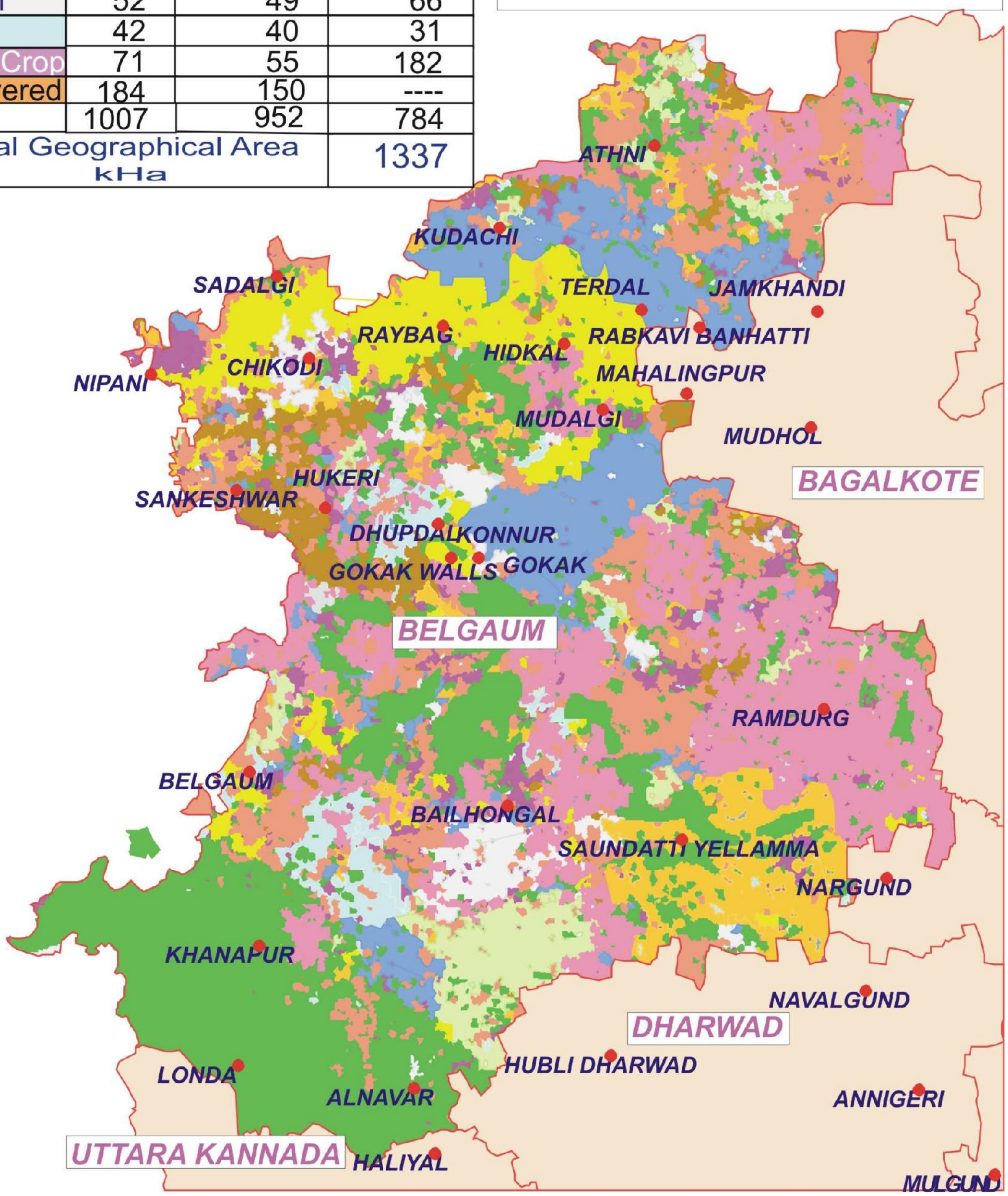


Table 7.1: Power Potential over All Agricultural Crops in India

State	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Uttar Pradesh	24136.50	100648.23	76287.10	24361.13	2919.44
Punjab	6877.30	49972.08	27940.87	22031.20	2539.58
Madhya Pradesh	19309.40	44749.66	33238.04	11511.62	1423.42
Tamil nadu	14827.20	45172.46	29963.43	15209.03	1357.64
Rajasthan	15518.80	34056.38	23688.09	10368.30	1294.28
Haryana	4948.50	27493.47	17526.88	9966.59	1171.67
Karnataka	8068.46	24597.81	16107.87	8489.94	1096.69
Gujarat	8424.20	29363.60	22317.15	7046.45	880.63
Bihar	8971.50	29013.30	22809.52	6203.79	710.35
Andhra Pradesh	11963.80	37157.02	31685.38	5471.64	648.98
Kerala	1604.00	8477.05	3546.07	4930.99	639.80
Maharashtra	12672.80	27834.04	23244.70	4589.34	570.14
West Bengal	7912.90	35139.22	30503.12	4636.10	558.60
Assam	3235.20	10069.35	8886.27	1183.08	137.35
Orissa	5211.20	10136.16	8944.56	1191.59	133.65
Meghalaya	205.30	646.94	547.00	99.94	11.08
Arunachal Pradesh	188.40	381.08	339.33	41.75	5.08
Sikkim	61.40	149.49	132.28	17.21	2.21
Mizoram	10.50	43.41	38.68	4.73	0.62
Total	**154147.36**	**515100.76**	**377746.32**	**137354.43**	**16101.21**

Note: Power below 200 kW per district has not been considered

Table 7.2: Power Potential for all the Districts in Karnataka

District	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Belgaum	788.65	2579.80	1597.62	982.18	129.35
Tumkur	618.29	2115.17	1123.33	991.84	125.09
Gulbarga	1333.68	2342.84	1563.01	779.83	102.70
Chitradurga	476.29	1412.50	698.15	714.35	92.43
Bellary	538.97	1860.29	1174.61	685.69	89.91
Bijapur	837.99	1915.89	1247.47	668.41	88.16
Dharwad	419.81	1325.55	682.85	642.70	86.82
Mysore	386.25	1711.02	1090.65	620.36	81.98
Raichur	639.16	2045.91	1449.63	596.28	76.55
Hassan	358.10	1260.76	894.84	365.92	45.37
Shimoga	241.65	1410.93	1074.46	336.47	41.62
Kolar	288.83	894.46	640.54	253.91	32.37
Mandya	233.50	1003.23	805.67	197.56	23.37
Chikmagalur	231.28	695.54	521.48	174.06	21.53
Bidar	333.94	482.33	345.57	136.76	17.89
Uttarakannada	121.74	544.47	407.36	137.11	16.85
Dakshinakannada	106.65	502.78	382.07	120.70	14.56
Kodagu	43.36	276.61	230.17	46.43	5.27
Bangalore	70.30	217.74	178.37	39.37	4.89
Total	**8068.46**	**24597.81**	**16107.87**	**8489.94**	**1096.69**

Note: Power below 200 kW per district has not been considered

Table 7.3: Power Potential for all the Crops in Belgaum District (Karnataka)

Crop name	Residue name	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Cotton	Stalks	65.83	296.23	59.25	236.98	33.18
Maize	Stalks	109.37	540.29	324.17	216.12	28.09
Ground nut	Stalks	86.02	170.32	51.10	119.22	15.50
Jowar	Cobs	192.49	133.46	26.69	106.77	14.95
Jowar	Stalks	192.49	453.76	408.39	45.38	5.90
Maize	Cobs	109.37	81.04	40.52	40.52	5.67
Wheat	Pod	54.40	55.32	16.60	38.73	4.65
Paddy	Stalks	62.73	355.68	320.12	35.57	3.91
Wheat	Stalks	54.40	92.21	64.54	27.66	3.32
Jowar	Husk	192.49	53.38	26.69	26.69	3.20
Paddy	Husk	62.73	47.42	23.71	23.71	2.61
Bajra	Stalks	30.89	17.92	5.38	12.54	1.63
Potato	Leaves	5.32	57.03	45.62	11.41	1.54
Ground nut	Shell	86.02	25.55	12.77	12.77	1.53
Soyabean	Stalks	53.05	100.11	90.10	10.01	1.35
Sunflower	Stalks	28.03	24.85	19.88	4.97	0.65
Bajra	Cobs	30.89	2.96	0.59	2.37	0.31
Gram	Stalks	24.20	19.70	17.73	1.97	0.24
Arhar	Stalks	8.60	9.03	7.23	1.81	0.23
	Total	**720.94**	**2536.27**	**1561.07**	**975.20**	**128.46**

Note: Power below 200 kW per crop residue has not been considered

Table 7.4: Power Potential for Corn Cobs in India

State	District	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Andhra Pradesh	Karimnagar	96.50	114.79	45.91	68.87	9.64
Andhra Pradesh	Medak	80.10	91.91	36.77	55.15	7.72
Andhra Pradesh	Nizamabad	55.30	60.89	24.35	36.53	5.11
Andhra Pradesh	Warangal	45.40	43.92	17.57	26.35	3.69
Andhra Pradesh	Adilabad	29.30	28.88	11.55	17.33	2.43
Andhra Pradesh	Mahbubnagar	20.60	23.30	9.32	13.98	1.96
Andhra Pradesh	Khammam	18.50	17.90	7.16	10.74	1.50
Andhra Pradesh	West Godavari	9.70	10.45	4.18	6.27	0.88
Andhra Pradesh	Prakasam	5.70	6.75	2.70	4.05	0.57
Andhra Pradesh	Rangareddy	6.10	6.10	2.44	3.66	0.51
Andhra Pradesh	Visakhapatnam	6.70	6.04	2.42	3.62	0.51
Andhra Pradesh	East Godavari	5.50	5.81	2.32	3.48	0.49
Andhra Pradesh	Guntur	5.10	5.42	2.17	3.25	0.45
Andhra Pradesh	Krishna	4.70	5.03	2.01	3.02	0.42
Andhra Pradesh	Anantapur	3.60	3.97	1.59	2.38	0.33
Andhra Pradesh	Vizianagaram	2.40	2.55	1.02	1.53	0.21
Bihar	Begusarai	70.00	41.79	37.61	4.18	0.59
Bihar	Samastipur	47.00	33.28	29.95	3.33	0.47
Bihar	Madhepura	41.20	32.63	29.37	3.26	0.46
Bihar	Khagaria	46.70	28.49	25.64	2.85	0.40
Bihar	Vaishali	34.60	19.69	17.72	1.97	0.28
Bihar	Saharsa	38.20	19.21	17.29	1.92	0.27
Bihar	Purnea	31.10	19.19	17.27	1.92	0.27
Bihar	Muzaffarpur	33.90	18.48	16.63	1.85	0.26
Bihar	Katihar	23.30	17.34	15.60	1.73	0.24
Bihar	Purba Chamaparan	22.00	17.31	15.58	1.73	0.24
Gujarat	Panchmahals	201.80	91.42	45.71	45.71	6.40
Gujarat	Sabarkantha	122.10	73.26	36.63	36.63	5.13
Gujarat	Vadodara	46.60	23.49	11.74	11.74	1.64
Gujarat	Banaskantha	6.80	3.90	1.95	1.95	0.27
Haryana	Panchkula	11.00	6.60	3.30	3.30	0.46
Haryana	Ambala	6.00	3.29	1.65	1.65	0.23
Karnataka	Belgaum	109.37	81.04	40.52	40.52	5.67

Karnataka	Chitradurga	33.39	25.01	12.50	12.50	1.75
Karnataka	Bellary	32.09	23.97	11.99	11.99	1.68
Karnataka	Mysore	17.60	15.00	7.50	7.50	1.05
Karnataka	Dharwad	18.57	14.09	7.05	7.05	0.99
Karnataka	Kolar	14.02	10.84	5.42	5.42	0.76
Karnataka	Bijapur	12.17	10.02	5.01	5.01	0.70
Karnataka	Shimoga	8.30	6.76	3.38	3.38	0.47
Karnataka	Tumkur	6.22	4.30	2.15	2.15	0.30
Karnataka	Hassan	5.24	3.97	1.98	1.98	0.28
Madhya Pradesh	Jhabua	104.50	44.83	40.35	4.48	0.63
Madhya Pradesh	Chhindwara	55.40	37.56	33.81	3.76	0.53
Madhya Pradesh	Mandsaur	60.10	31.01	27.91	3.10	0.43
Madhya Pradesh	Dhar	66.30	26.85	24.17	2.69	0.38
Madhya Pradesh	Ratlam	46.80	23.03	20.72	2.30	0.32
Madhya Pradesh	Rajgarh	45.00	17.55	15.80	1.75	0.25
Madhya Pradesh	Surguja	36.40	16.93	15.23	1.69	0.24
Maharashtra	Aurangabad	44.80	22.89	20.60	2.29	0.32
Maharashtra	Jalna	36.90	19.11	17.20	1.91	0.27
Maharashtra	Solapur	30.60	16.55	14.90	1.66	0.23
Orissa	Naworangpur	19.90	10.87	6.52	4.35	0.61
Punjab	Hoshiarpur	63.00	42.34	29.64	12.70	1.78
Punjab	Rupnagar	26.00	15.60	10.92	4.68	0.66
Punjab	N.Shahar	18.00	12.91	9.03	3.87	0.54
Punjab	Jalandhar	13.00	10.22	7.15	3.07	0.43
Punjab	Gurdaspur	14.00	9.28	6.50	2.78	0.39
Rajasthan	Udaipur	169.70	72.29	57.83	14.46	2.02
Rajasthan	Chittaurgarh	142.30	58.91	47.13	11.78	1.65
Rajasthan	Banswara	108.50	52.08	41.66	10.42	1.46
Rajasthan	Dungarpur	62.10	24.22	19.38	4.84	0.68
Rajasthan	Bhilwara	151.20	24.04	19.23	4.81	0.67
Rajasthan	Rajsamand	61.60	13.86	11.09	2.77	0.39
Rajasthan	Jhalawar	43.50	13.70	10.96	2.74	0.38
Rajasthan	Waren	19.00	8.26	6.61	1.65	0.23
Rajasthan	Bundi	31.50	7.56	6.05	1.51	0.21
Tamil Nadu	Dindigul Anna	21.80	12.88	5.15	7.73	1.08
Tamil Nadu	Coimbatore	18.80	6.37	2.55	3.82	0.54
Tamil Nadu	Theni	7.00	4.26	1.71	2.56	0.36
Tamil Nadu	Erode	4.40	3.00	1.20	1.80	0.25

Tamil Nadu	Virudunagar	4.10	2.48	0.99	1.49	0.21
Uttar Pradesh	Bulandshahr	78.80	26.59	13.30	13.30	1.86
Uttar Pradesh	Kannauj	44.20	21.61	10.81	10.81	1.51
Uttar Pradesh	Farrukhabad	50.20	20.33	10.17	10.17	1.42
Uttar Pradesh	Etah	54.40	20.16	10.08	10.08	1.41
Uttar Pradesh	Jaunpur	48.20	18.73	9.36	9.36	1.31
Uttar Pradesh	Bharaich	64.20	17.53	8.76	8.76	1.23
Uttar Pradesh	Aligarh	41.60	13.85	6.93	6.93	0.97
Uttar Pradesh	Gonda	69.80	13.51	6.75	6.75	0.95
Uttar Pradesh	Hardoi	41.70	13.39	6.69	6.69	0.94
Uttar Pradesh	Unnao	36.00	9.99	5.00	5.00	0.70
Uttar Pradesh	Mainpuri	25.50	9.33	4.67	4.67	0.65
Uttar Pradesh	Kanpur Nagar	16.40	8.36	4.18	4.18	0.59
Uttar Pradesh	Lalitpur	19.70	7.92	3.96	3.96	0.55
Uttar Pradesh	Shravasti	33.90	7.27	3.64	3.64	0.51
Uttar Pradesh	Ballia	24.60	6.97	3.49	3.49	0.49
Uttar Pradesh	Nainital	9.70	5.12	2.56	2.56	0.36
Uttar Pradesh	Sonbhadra	12.80	4.92	2.46	2.46	0.34
Uttar Pradesh	G.Buddha Ngr	9.00	4.67	2.34	2.34	0.33
Uttar Pradesh	Dehradun	9.30	3.74	1.87	1.87	0.26
Uttar Pradesh	Budaun	12.50	3.71	1.86	1.86	0.26
Uttar Pradesh	Sitapur	19.70	3.61	1.80	1.80	0.25
Uttar Pradesh	Auraiya	13.10	3.58	1.79	1.79	0.25
West Bengal	Darjiling	21.50	23.28	9.31	13.97	1.96
West Bengal	Malda	7.60	8.19	3.27	4.91	0.69
	Total	**3725.06**	**2015.85**	**1261.63**	**754.22**	**105.59**

Table 7.5: Power Potential for Coconut Fronds in India

State	District	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Assam	Nowgaon	5.00	37.35	18.68	18.68	2.24
Assam	Kamrup	1.90	13.95	6.98	6.98	0.84
Assam	Nalbari	2.00	9.15	4.57	4.57	0.55
Assam	Sonitpur	1.30	9.00	4.50	4.50	0.54
Assam	Marigaon	1.40	7.05	3.52	3.52	0.42
Assam	Barpeta	1.10	6.07	3.04	3.04	0.36
Assam	Cachar	1.40	5.03	2.51	2.51	0.30
Assam	Golaghat	0.60	3.75	1.87	1.87	0.22
Assam	Darrang	0.90	3.67	1.84	1.84	0.22
Assam	Dhubri	0.70	3.38	1.69	1.69	0.20
Karnataka	Tumkur	83.82	413.64	82.73	330.91	39.71
Karnataka	Hassan	48.84	202.95	40.59	162.36	19.48
Karnataka	Chitradurga	36.61	160.62	32.12	128.50	15.42
Karnataka	Mandya	16.76	60.09	12.02	48.07	5.77
Karnataka	Chikmagalur	30.04	56.78	11.36	45.42	5.45
Karnataka	Dakshinakannada	12.83	41.08	8.22	32.86	3.94
Karnataka	Mysore	11.82	31.56	6.31	25.25	3.03
Karnataka	Uttarakannada	5.62	20.08	4.02	16.06	1.93
Karnataka	Shimoga	6.64	17.57	3.51	14.06	1.69
Karnataka	Bangalore	3.35	12.00	2.40	9.60	1.15
Karnataka	Kolar	2.10	7.52	1.50	6.01	0.72
Karnataka	Bellary	1.17	4.21	0.84	3.37	0.40
Karnataka	Gulbarga	0.75	2.82	0.56	2.26	0.27
Karnataka	Kodagu	0.78	2.78	0.56	2.23	0.27
Kerala	Kozhikode	144.50	791.14	395.57	395.57	47.47
Kerala	Cannanore	143.40	770.06	385.03	385.03	46.20
Kerala	Malappuram	123.10	768.14	384.07	384.07	46.09
Kerala	Trichur	103.50	522.42	261.21	261.21	31.34
Kerala	Thiruvananthapuram	110.50	444.21	222.10	222.10	26.65
Kerala	Alappuzha	77.20	293.55	146.78	146.78	17.61
Kerala	Ernakulam	57.70	290.38	145.19	145.19	17.42
Kerala	Kollam	73.60	290.35	145.18	145.18	17.42
Kerala	Kasargod	54.80	242.90	121.45	121.45	14.57
Kerala	Palghat	54.20	175.61	87.80	87.80	10.54
Kerala	Kottayam	47.70	153.12	76.56	76.56	9.19
Kerala	Wayanand	30.20	117.78	58.89	58.89	7.07
Kerala	Pathanamthitta	26.00	101.20	50.60	50.60	6.07
Kerala	Idukki	31.00	82.54	41.27	41.27	4.95
West Bengal	North 24 Parganas	3.00	41.76	20.88	20.88	2.51
West Bengal	Haora	3.00	39.08	19.54	19.54	2.34
West Bengal	South 24 Parganas	3.50	31.37	15.68	15.68	1.88
West Bengal	Medinipur (East)	3.20	24.94	12.47	12.47	1.50
West Bengal	Barddhaman	1.90	20.73	10.37	10.37	1.24
West Bengal	Murshidabad	4.20	18.27	9.14	9.14	1.10
West Bengal	Hugli	1.00	15.76	7.88	7.88	0.95
West Bengal	Medinipur (West)	1.00	12.70	6.35	6.35	0.76
West Bengal	Jalpaiguri	1.10	11.75	5.87	5.87	0.70
West Bengal	Nadia	0.80	8.63	4.31	4.31	0.52
West Bengal	Kochbihar	0.60	5.40	2.70	2.70	0.32
	Total	**1378.13**	**6405.88**	**2892.83**	**3513.05**	**421.57**

Table 7.6: Power Potential for Coconut Shell in India

State	District	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Assam	Nowgaon	5.00	8.47	1.69	6.77	0.95
Assam	Kamrup	1.90	3.16	0.63	2.53	0.35
Assam	Nalbari	2.00	2.07	0.41	1.66	0.23
Assam	Sonitpur	1.30	2.04	0.41	1.63	0.23
Karnataka	Tumkur	83.82	93.76	18.75	75.01	10.50
Karnataka	Hassan	48.84	46.00	9.20	36.80	5.15
Karnataka	Chitradurga	36.61	36.41	7.28	29.13	4.08
Karnataka	Mandya	16.76	13.62	2.72	10.90	1.53
Karnataka	Chikmagalur	30.04	12.87	2.57	10.30	1.44
Karnataka	Dakshinakannada	12.83	9.31	1.86	7.45	1.04
Karnataka	Mysore	11.82	7.15	1.43	5.72	0.80
Karnataka	Uttarakannada	5.62	4.55	0.91	3.64	0.51
Karnataka	Shimoga	6.64	3.98	0.80	3.19	0.45
Karnataka	Bangalore	3.35	2.72	0.54	2.18	0.30
Kerala	Kozhikode	144.50	179.32	35.86	143.46	20.08
Kerala	Cannanore	143.40	174.55	34.91	139.64	19.55
Kerala	Malappuram	123.10	174.11	34.82	139.29	19.50
Kerala	Trichur	103.50	118.41	23.68	94.73	13.26
Kerala	Thiruvananthapuram	110.50	100.69	20.14	80.55	11.28
Kerala	Alappuzha	77.20	66.54	13.31	53.23	7.45
Kerala	Ernakulam	57.70	65.82	13.16	52.65	7.37
Kerala	Kollam	73.60	65.81	13.16	52.65	7.37
Kerala	Kasargod	54.80	55.06	11.01	44.05	6.17
Kerala	Palghat	54.20	39.80	7.96	31.84	4.46
Kerala	Kottayam	47.70	34.71	6.94	27.77	3.89
Kerala	Wayanand	30.20	26.70	5.34	21.36	2.99
Kerala	Pathanamthitta	26.00	22.94	4.59	18.35	2.57
Kerala	Idukki	31.00	18.71	3.74	14.97	2.10
West Bengal	North 24 Parganas	3.00	9.47	1.89	7.57	1.06
West Bengal	Haora	3.00	8.86	1.77	7.09	0.99
West Bengal	South 24 Parganas	3.50	7.11	1.42	5.69	0.80
West Bengal	Medinipur (East)	3.20	5.65	1.13	4.52	0.63
West Bengal	Barddhaman	1.90	4.70	0.94	3.76	0.53
West Bengal	Murshidabad	4.20	4.14	0.83	3.31	0.46
West Bengal	Hugli	1.00	3.57	0.71	2.86	0.40
West Bengal	Medinipur (West)	1.00	2.88	0.58	2.30	0.32
West Bengal	Jalpaiguri	1.10	2.66	0.53	2.13	0.30
West Bengal	Nadia	0.80	1.96	0.39	1.56	0.22
	Total	**1366.63**	**1440.29**	**288.06**	**1152.23**	**161.31**

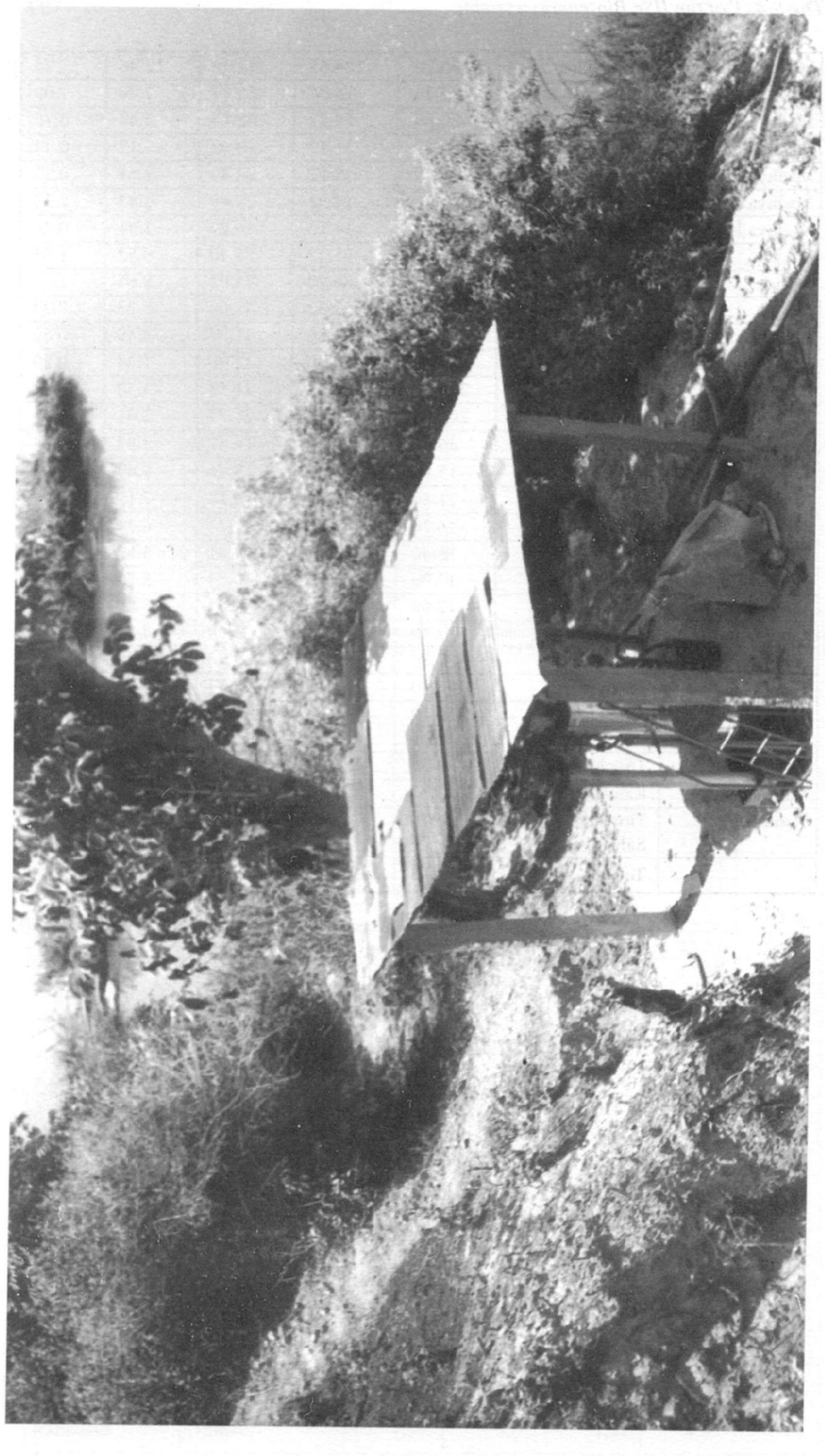
Note: Power below 200 kW per crop per district has not been considered

Table 7.7: Power Potential for Cotton Stalks in India

State	District	Crop Area kHa	Residue Generation kT	Utilization kT	Excess Biomass kT	Power MW
Andhra Pradesh	Warangal	146.30	149.23	134.30	14.92	2.09
Andhra Pradesh	Karimnagar	84.30	98.63	88.77	9.86	1.38
Andhra Pradesh	Adilabad	162.10	77.81	70.03	7.78	1.09
Andhra Pradesh	Khammam	88.10	74.00	66.60	7.40	1.04
Andhra Pradesh	Kurnool	153.70	73.78	66.40	7.38	1.03
Andhra Pradesh	Nalgonda	112.70	64.24	57.82	6.42	0.90
Andhra Pradesh	Guntur	193.60	63.89	57.50	6.39	0.89
Andhra Pradesh	Prakasam	62.80	41.45	37.30	4.14	0.58
Andhra Pradesh	Mahbubnagar	93.60	39.31	35.38	3.93	0.55
Andhra Pradesh	Medak	22.60	16.27	14.64	1.63	0.23
Andhra Pradesh	Krishna	41.30	16.11	14.50	1.61	0.23
Andhra Pradesh	Nizamabad	20.00	14.40	12.96	1.44	0.20
Bihar	Siwan	4.30	4.51	1.35	3.16	0.44
Gujarat	Surendranagar	409.00	392.64	117.79	274.85	38.48
Gujarat	Rajkot	153.10	289.36	86.81	202.55	28.36
Gujarat	Bhavnagar	195.60	211.25	63.37	147.87	20.70
Gujarat	Amreli	90.10	189.21	56.76	132.45	18.54
Gujarat	Vadodara	177.00	185.85	55.76	130.10	18.21
Gujarat	Ahmedabad	178.80	150.19	45.06	105.13	14.72
Gujarat	Bharuch	140.90	143.72	43.12	100.60	14.08
Gujarat	Jamnagar	47.60	105.67	31.70	73.97	10.36
Gujarat	Mahesana	107.60	96.84	29.05	67.79	9.49
Gujarat	Kachchh	48.00	60.48	18.14	42.34	5.93
Gujarat	Sabarkantha	35.40	48.85	14.66	34.20	4.79
Gujarat	Junagadh	22.20	48.62	14.59	34.03	4.76
Gujarat	Banaskantha	23.90	18.64	5.59	13.05	1.83
Gujarat	Gandhinagar	5.40	10.21	3.06	7.14	1.00
Gujarat	Panchmahals	6.10	8.05	2.42	5.64	0.79
Gujarat	Surat	2.70	3.89	1.17	2.72	0.38
Haryana	Sirsa	212.00	159.00	135.15	23.85	3.34
Haryana	Hisar	140.00	105.00	89.25	15.75	2.21
Haryana	Fatehabad	102.00	82.62	70.23	12.39	1.74
Haryana	Bhiwani	55.00	49.50	42.08	7.43	1.04
Haryana	Jind	46.00	34.50	29.32	5.18	0.72
Karnataka	Dharwad	86.88	482.16	96.43	385.72	54.00
Karnataka	Mysore	59.67	458.25	91.65	366.60	51.32
Karnataka	Belgaum	65.83	296.23	59.25	236.98	33.18
Karnataka	Bellary	66.41	257.01	51.40	205.61	28.79
Karnataka	Raichur	49.21	175.67	35.13	140.54	19.68
Karnataka	Shimoga	18.01	126.98	25.40	101.58	14.22
Karnataka	Gulbarga	20.11	115.85	23.17	92.68	12.98
Karnataka	Chitradurga	26.80	90.84	18.17	72.67	10.17
Karnataka	Uttarakannada	6.29	44.50	8.90	35.60	4.98
Karnataka	Bijapur	8.73	37.96	7.59	30.37	4.25
Karnataka	Hassan	5.22	17.09	3.42	13.67	1.91
Karnataka	Chikmagalur	3.27	14.72	2.94	11.77	1.65
Karnataka	Bidar	3.62	10.31	2.06	8.24	1.15
Karnataka	Tumkur	1.34	6.04	1.21	4.83	0.68
Madhya Pradesh	West Nimar	166.20	124.65	112.18	12.46	1.75
Madhya Pradesh	Dhar	73.30	76.96	69.27	7.70	1.08

Madhya Pradesh	East Nimar	120.60	54.27	48.84	5.43	0.76
Madhya Pradesh	Wadwani	45.20	31.19	28.07	3.12	0.44
Madhya Pradesh	Dewas	29.90	25.12	22.60	2.51	0.35
Madhya Pradesh	Chhindwara	15.30	24.33	21.89	2.43	0.34
Madhya Pradesh	Ratlam	20.80	18.10	16.29	1.81	0.25
Punjab	Firozpur	138.00	95.22	85.70	9.52	1.33
Punjab	Bathinda	170.00	86.70	78.03	8.67	1.21
Punjab	Mukatsar	109.00	52.32	47.09	5.23	0.73
Punjab	Mansha	83.00	34.86	31.37	3.49	0.49
Punjab	Sangrur	24.00	14.40	12.96	1.44	0.20
Rajasthan	Ganganagar	291.90	35.03	31.53	3.50	0.49
Rajasthan	Hanumangarh	201.20	24.14	21.73	2.41	0.34
Tamil Nadu	Virudunagar	36.60	25.25	16.42	8.84	1.24
Tamil Nadu	Villupuram	15.80	21.33	13.86	7.47	1.05
Tamil Nadu	Perambalur	21.80	20.27	13.18	7.10	0.99
Tamil Nadu	Salem	16.70	18.04	11.72	6.31	0.88
Tamil Nadu	Coimbatore	15.40	16.63	10.81	5.82	0.81
Tamil Nadu	Dharmapuri	19.00	16.53	10.74	5.79	0.81
Tamil Nadu	Dindigul Anna	12.60	16.25	10.57	5.69	0.80
Tamil Nadu	Madurai	17.10	13.85	9.00	4.85	0.68
Tamil Nadu	Erode	10.80	12.31	8.00	4.31	0.60
Tamil Nadu	Theni	8.90	10.95	7.12	3.83	0.54
Tamil Nadu	Tirunelveli Kottabommam	12.20	9.52	6.19	3.33	0.47
Tamil Nadu	Tiruchirapalli	7.30	6.57	4.27	2.30	0.32
Tamil Nadu	Ramanathapuram	5.40	4.54	2.95	1.59	0.22
Tamil Nadu	Tiruvanna Malai Sambuvara	4.30	4.39	2.85	1.54	0.21
	Total	**5497.48**	**6155.03**	**2794.58**	**3360.45**	**470.46**

Note: Power below 200 kW per crop per district has not been considered



8

Hydrogen sulphide scrubbing – ISET Proces

Introduction

Biogas a mixture of Methane, Carbon dioxide and Hydrogen sulfide is produced in the biomethanation plant used for pollution control, such as distillery effluent treatment, sewage treatment plants, where the effluent is digested anaerobically. Biogas from these plants contains Methane, CH_4, (55-65 %), Carbondioxide, CO_2, (30 - 40 %) and hydrogen sulfide, H_2S, (2-8%). Such a gas is also called sour gas. Biogas from the biomethanation plants with calorific value of 4000 – 5000 kcal/ m^3 is a potential fuel for power generation in gas engines, dual fuel engines or in boilers. Biogas should be cleaned for hydrogen sulfide before using it in any of the said systems to avoid corrosion in the engine parts and to reduce pollution (H_2S when burned gives out SO_2, which is one of the reasons for the formation of fog and acid rains).

Process Principle

ISET process developed by ABETS, IISc is based on the red-ox reaction of chelated polyvalent metal ion. In this particular process iron in aqueous medium, which exists in both Fe^{3+} and Fe^{2+} form, is used for scrubbing hydrogen sulfide from the biogas. The sulfur present in the hydrogen sulfide is precipitated as elemental sulfur.

Process Chemistry

H_2S when dissolved in aqueous medium is ionized to H^+ and S^{2-}. The sulphur ions can be oxidized by polyvalent metal ions such as those of iron, which can exist in both ferric (Fe^{3+}) and ferrous (Fe^{2+}) state. When the sulphur ion comes in contact with ferric ion complex, it gets oxidized to elemental sulphur and is precipitated.

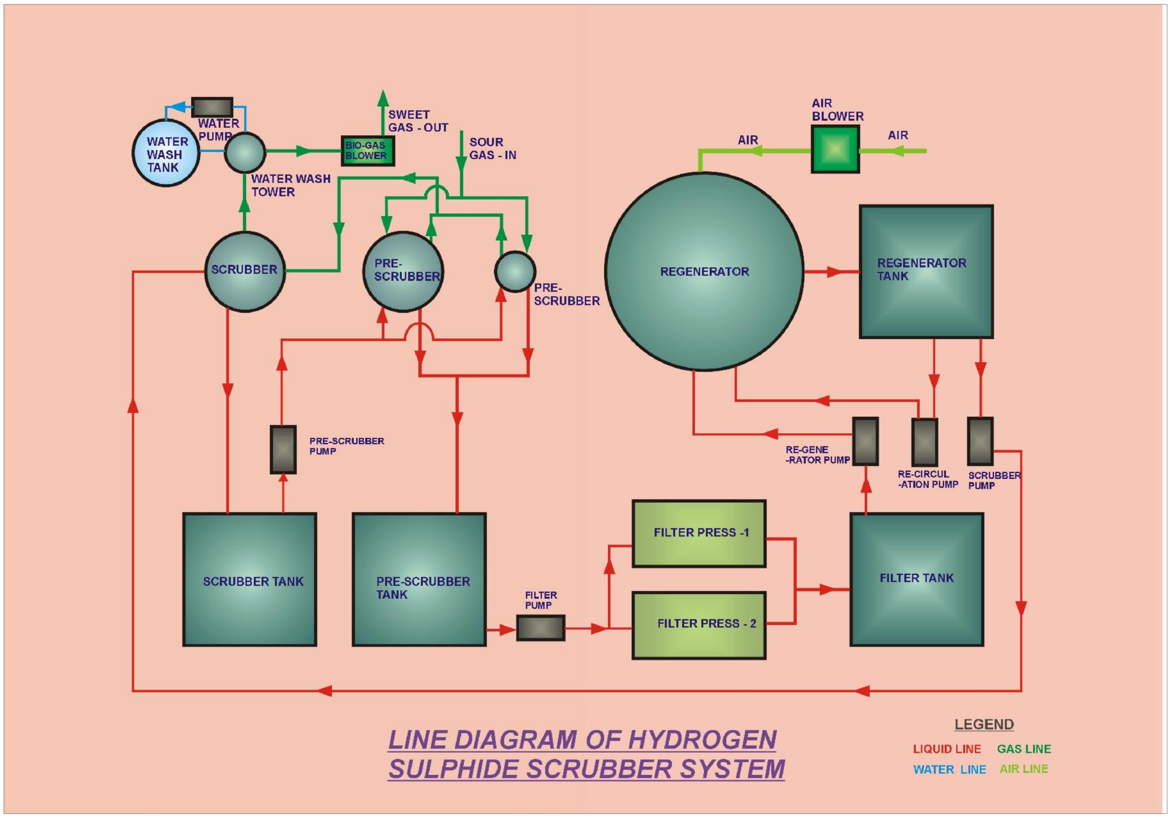
$$2Fe^{3+} + S^{2-} \longrightarrow 2Fe^{2+} + S$$

The ferrous ions are later oxidized to ferric ions by reaction with oxygen in the atmospheric air.

$$4Fe^{2+} + 4H^+ + O_2 \longrightarrow 4Fe^{3+} + 2H_2O$$

Process Description

The process uses the counter current gas liquid contacting with the gas being taken from the bottom of the packed scrubber column and the scrubbed liquid is pumped form the top in a two stage scrubbing operation. The gas coming out of the scrubber column, which is free of hydrogen sulfide, is then scrubbed with water for cleaning any minute quantities of chemical carried over. The clean gas thus obtained is fit for the end application. The scrubbed solution containing sulfur is then passed through filter press for sulfur removal. The clear filtrate is then regenerated in a counter current with air in a packed re-generation column.



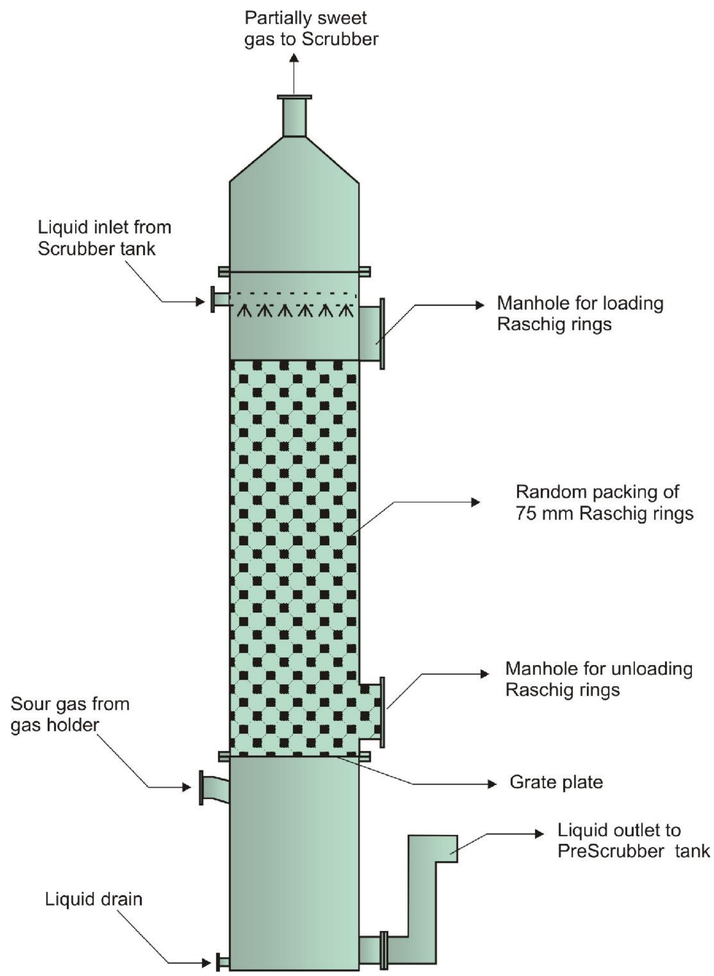
LINE DIAGRAM OF HYDROGEN SULPHIDE SCRUBBER SYSTEM

The System and its major elements:

a. Scrubber
b. Pre scrubber
c. Regeneration tower
d. Filter press
e. Wash tower
f. Biogas blower
g. Air blower
h. Pumps

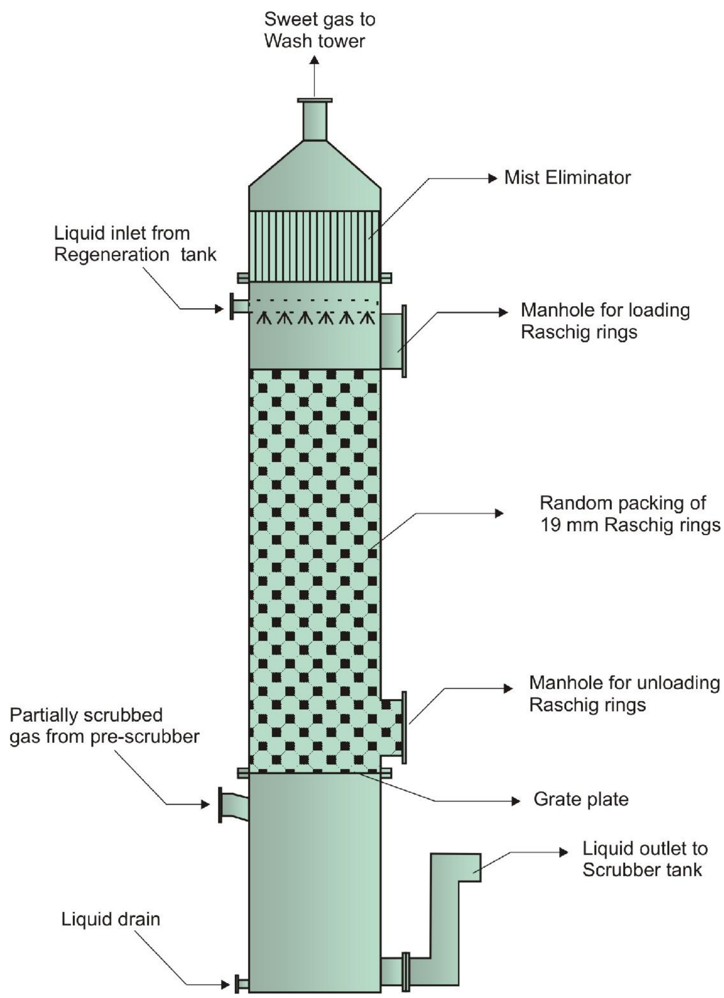
a. Scrubber

In this element, the gas cleaning operation is performed. The tower is packed with Raschig rings to ensure better contact between liquid and gas. A mist eliminator fitted at the top eliminates any liquid carry over by the gas. The material of construction of the column is either concrete with epoxy coating or PP lined FRP and is packed with PP Raschig rings.



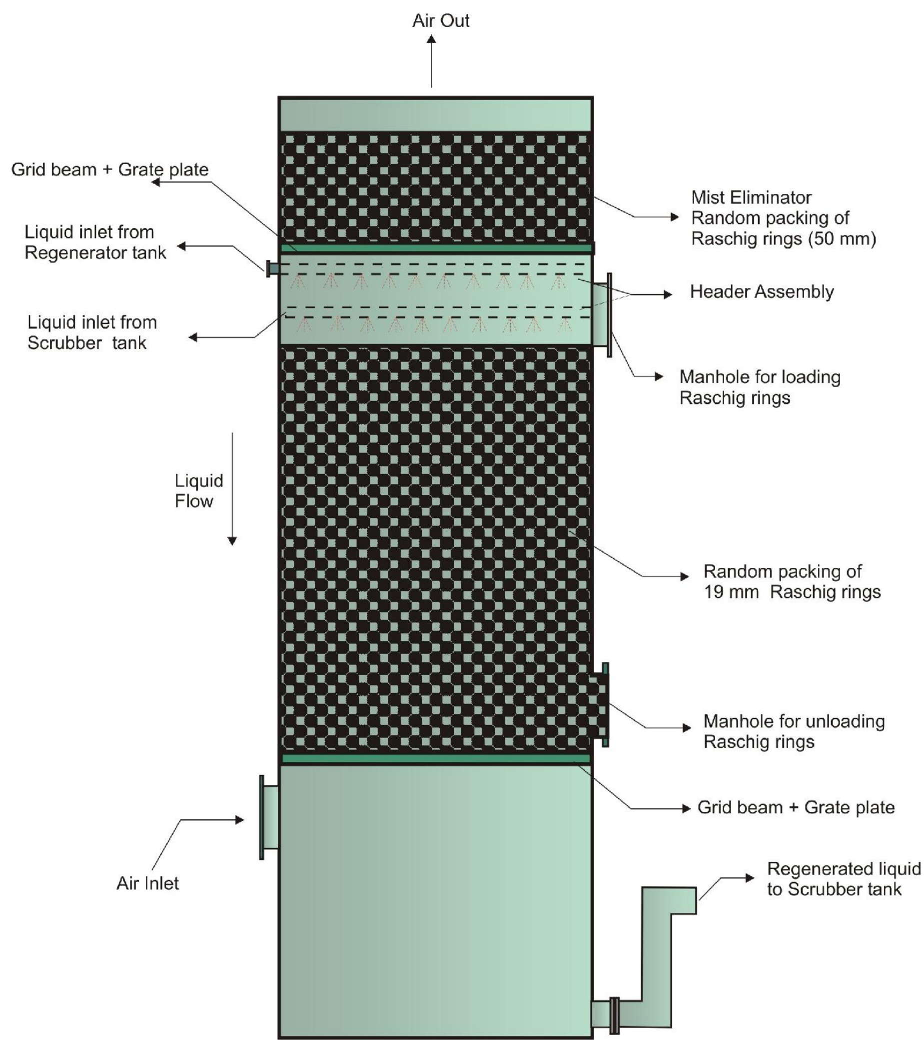
b. Pre scrubber

This element is similar to the scrubber. The difference is that it is packed tower with larger size Raschig rings. The raw gas enters this tower first and then enters the packed tower. Hence it minimizes the blockage of rings in the scrubber due to sulphur deposition. The material of construction of the unit is either concrete with epoxy coating or PP lined FRP and is packed with PP Raschig rings.



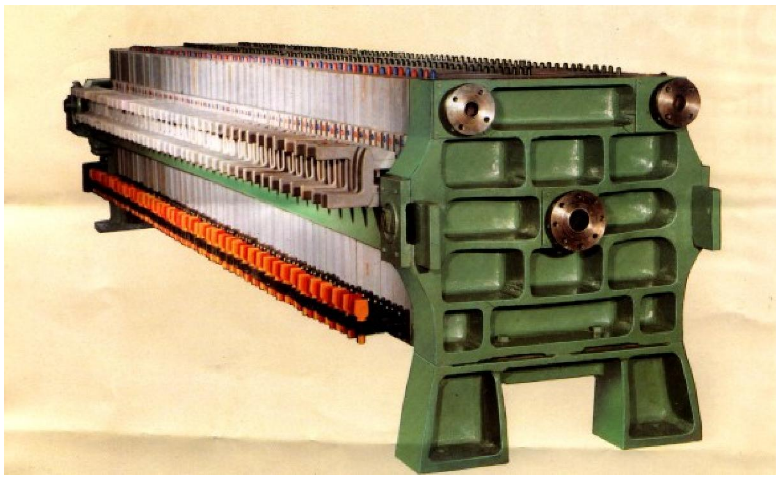
c. Regeneration tower

In this element, the regeneration of the scrubbing solution occurs. This tower is packed with Raschig rings to ensure good contact between air and liquid for maximum regeneration and this also takes care of the cooling of the scrubbed solution. A mist eliminator fitted at the top eliminates any liquid carry over by air. Liquid is injected from top and air is either blown in from the bottom or sucked from the top through the louvers. The column is constructed either of concrete coated with epoxy or PP lined FRP depending upon the volume of gas and the hydrogen sulfide present and is packed with PP Raschig rings.



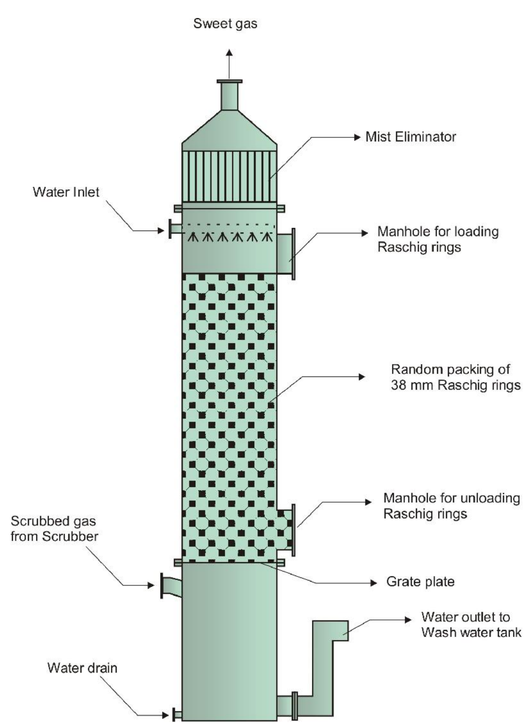
d. Filter Press

It is the sulphur separation stage. Sulphur precipitated during the cleaning process is filtered in the plate and frame filter press. The plates are polypropylene recessed plates over which filter cloth, which is also polypropylene, is put. The liquid with sulphur is passed through the plates and it gets filtered as it passes through the cloth. The sulphur is washed and later removed.



e. Wash tower

The scrubbed gas is cleaned of any minute quantity of scrubbing solution carried over by counter current contact of gas with water. The clean gas goes out of the unit after passing through the mist eliminator at the top. The tower is constructed of either concrete with epoxy coating or PP lined FRP and is packed with PP Raschig rings.



f. Biogas Blower

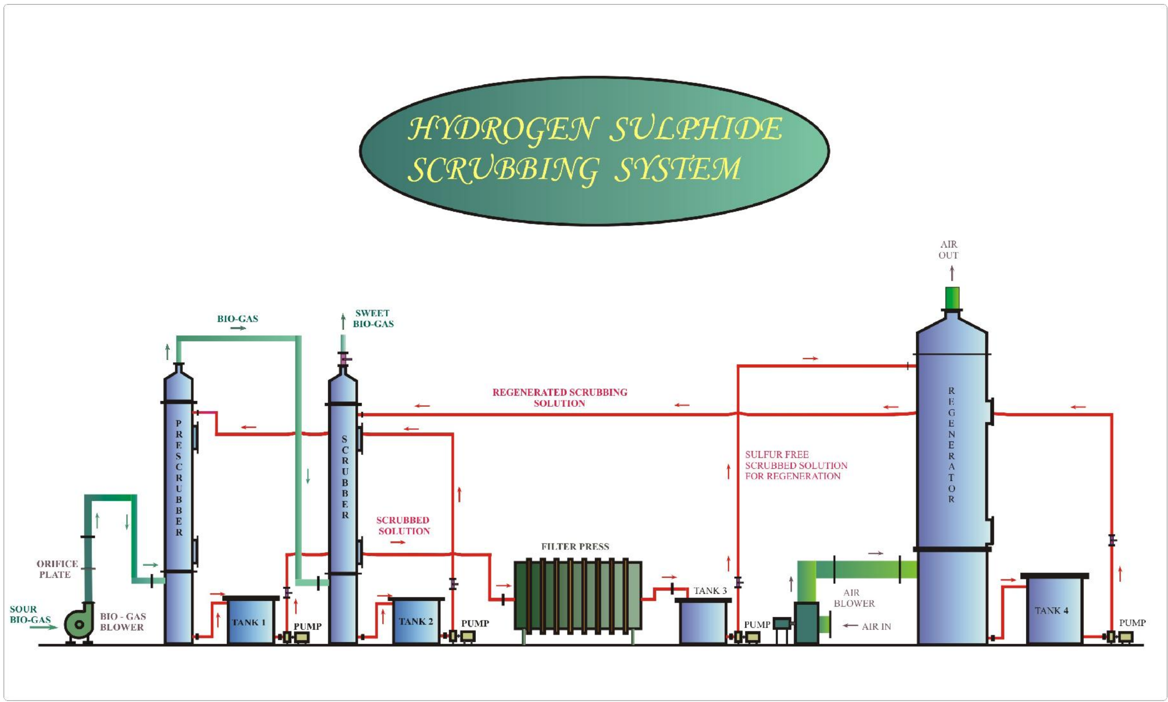
Biogas blower installed at the outlet of the scrubbed gas functions in maintaining the required gas flow rate and taking care of the pressure drop across the scrubber elements. This is made of MS with epoxy coating.

g. Air Blower

This is a component, which delivers the required airflow rate and pressure to the Regeneration Column for oxidizing the ferrous ion. This is made of MS with epoxy coating.

h. Pumps:

The pumps installed at various stages maintain the liquid flow rate across the different system elements. All parts coming in contact with the scrubbing solution are PP lined.



Advantages of this process

- H_2S is converted to solid Sulfur, which has commercial value.
- No gaseous emission
- Low H_2S content in the cleaned gas (<200 ppmv)
- The system is capable of handling fluctuations in H_2S concentration and biogas flow rate.
- This process is highly selective for H_2S with little CO_2 being removed.
- Simple to operate

Sulfur Quality and its utility

Contamination of sulfur by the gas will be minimum. Any contaminant by cleaning solution will be soluble in water and hence may be removed by washing with water. The sulfur particle produced in the process is typically 2 – 8 microns and a purity of more than 99 % is achieved. Sulfur for its good vulcanizing property is used in the rubber manufacture. The industrial grade of sulfur finds applications in paper and pulp, mining, steel, and oil refining. Sulfur is formulated for use as nutrients, soil amendments and pesticides. It can also be used in fungicide formulation and finds major application in pharmaceutical industries. This is also employed in sugar industries, petroleum refining and explosives. The sulfur precipitated in the process is wettable which has higher market value than the nonwettable grade.

Utility and Chemical requirements

i. **Electricity:** The connected electrical power for the pumps, blower and the filter will be about 8 to 10 % of the power generated
ii. **Cooling:** Any cooling requirement is taken care in the regeneration step itself.
iii. **Process water:** Process water for filter cake washing will be about 2m^3/ton of sulfur extracted.

Process control and operator requirements

The control system depends on the level of automation required. Intrinsically simple controls and minimal operator attention are sufficient.

Cost of electricity produced

The scrubbing chemicals are regenerated and only the make up chemical has to be added, thus making the process an economical one. The chemical cost of the system is dependent on the hydrogen sulphide concentration in the sour gas. At 3 % hydrogen sulphide concentration the total operating cost is around **Rs. 0.65/kWh**

Maintenance requirements

Maintenance requirements are minimum in this system as the sulfur suspended in the absorption column and the storage tank is filtered online.

Field Experiences

Pilot Plant at KCPSIC Ltd, Vuyyuru, Andhra Pradesh

Successful lab scale studies encouraged to take up a long term Pilot plant study. The pilot plant designed to handle 250 m^3/hr of biogas and 5 % H_2S was set up at KCPSIC Ltd. Studies were started in November 97 and initial design of Regeneration tower was changed from Spray tower to Packed tower during the studies as the regeneration of the scrubbing chemical was inadequate in the Spray tower. The other important input obtained during the study was the in adequacy of the centrifuge as filter used with settling tank for separation of sulphur from the scrubbing solution at higher hydrogen sulphide concentrations. This vital observation paved the way for filter press which was used for future systems.

Ugar Sugar Works Limited, Ugar Khurd, Belgaum, Karnataka

The first scrubbing system designed and commissioned for cleaning hydrogen sulphide from biogas produced using distillery effluent. The hydrogen sulphide concentration measured on an average is around 5 % and on the maximum reaching 6.5 – 7.0 %. Fabrication of scrubbing system components is done using PP lined FRP. Commissioned in the year 2000, the sweet gas from the system is used in the indigenously manufactured Greaves gas engines (4 nos) of 250 kWe each.

1. Designed biogas handling capacity:	600 m^3/hr
2. Designed power generation capacity:	1 MWe
3. Designed H_2S inlet concentration:	7.5 %
4. Measured H_2S inlet concentration:	4.5 – 6.0 %
5. Type of Engine used:	4 X 250 kWe S.I Gas Engine
6. Power generated till 31st March, 2003:	3.5 million kWh

KCPSIC Limited, Vuyyuru, Krishna District, Andhra Pradesh

The second system commissioned in late 2001 for scrubbing hydrogen sulphide from distillery effluent generated biogas is similar to the system at USWL in design. The system components differ in the material of construction. Regeneration tower and the tanks used in the process are constructed of RCC with epoxy coating on the surface for the required chemical resistance. This saved the cost of fabrication of these components to a considerable extent.

1. Designed biogas handling capacity: 600 m^3/hr
2. Designed power generation capacity: 1 MWe
3. Designed H_2S inlet concentration: 7.5 %
4. Measured H_2S inlet concentration: 4.5 – 6.5 %
5. Type of Engine used: 4 X 250 kWe S.I Gas Engine
6. Power generated till 31st March, 2003: 1.0 million kWh

UP Jal Nigam, Jajmau, Kanpur, Uttar Pradesh

This first commercial plant using ISET process was designed and commissioned for UP Jal Nigam, Kanpur for their 130 MLD sewage treatment plant at Jajmau. It consists of three systems of 300 m^3/hr integrated in parallel for a combined capacity of 900 m^3/hr. The fermentation in the digesters is carried out at ambient temperature. The power produced by the dual fuel engines serves in-house power need.

1. Designed biogas handling capacity:	900 m^3/hr
2. Designed power generation capacity:	1.5 MWe
3. Designed H_2S inlet concentration:	3.0 %
4. Measured H_2S inlet concentration:	1.0 – 1.5 %
5. Type of Engine used:	Dual fuel
6. Commissioned:	June 1999, running on an average of 4 - 6 hrs each day.

UP Jal Nigam, Naini, Allahabad, Uttar Pradesh

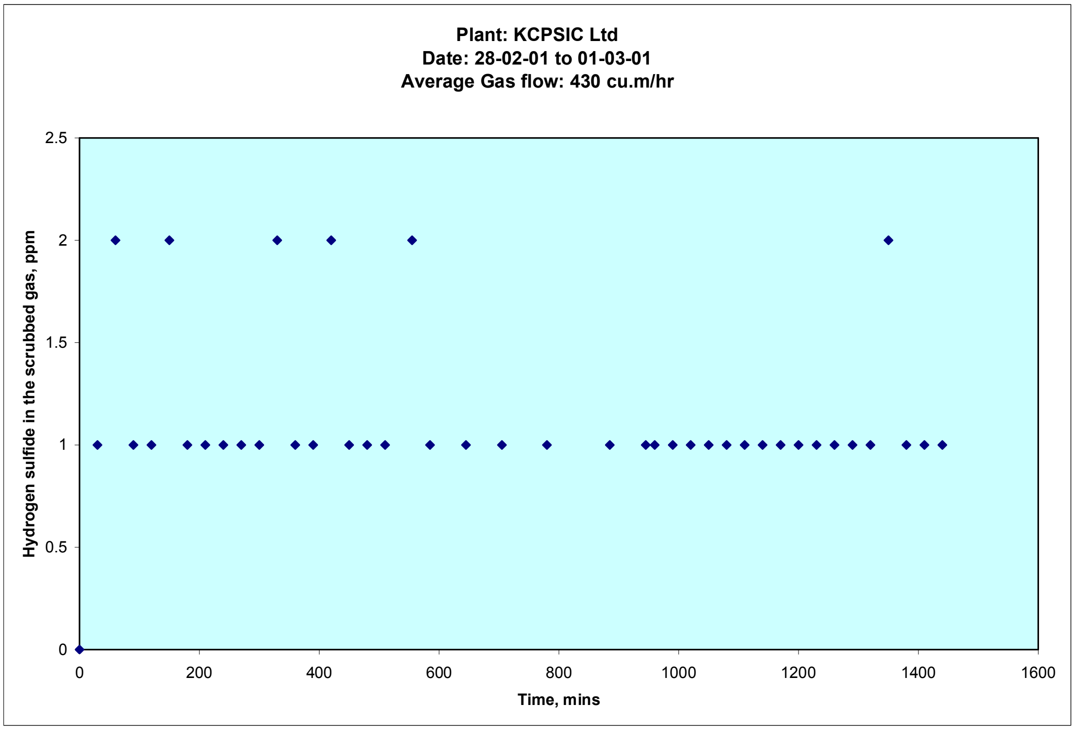
Almost the twin of the scrubbing system at UP Jal Nigam, Kanpur, this system is different only in the number of individual systems. Two systems of 300 m^3/hr is paralleled to give the desired output capacity as per the requirement of the client. This is also used to clean hydrogen sulphide from biogas generated from sewage treatment plant.

1. Designed biogas handling capacity:	600 m^3/hr
2. Designed power generation capacity:	1.0 MWe
3. Designed H_2S inlet concentration:	3.0 %
4. Measured H_2S inlet concentration:	< 0.75 %
5. Type of Engine used:	Dual fuel
6. Commissioned:	June 1999, running on an average of 4 – 6 hrs each day.

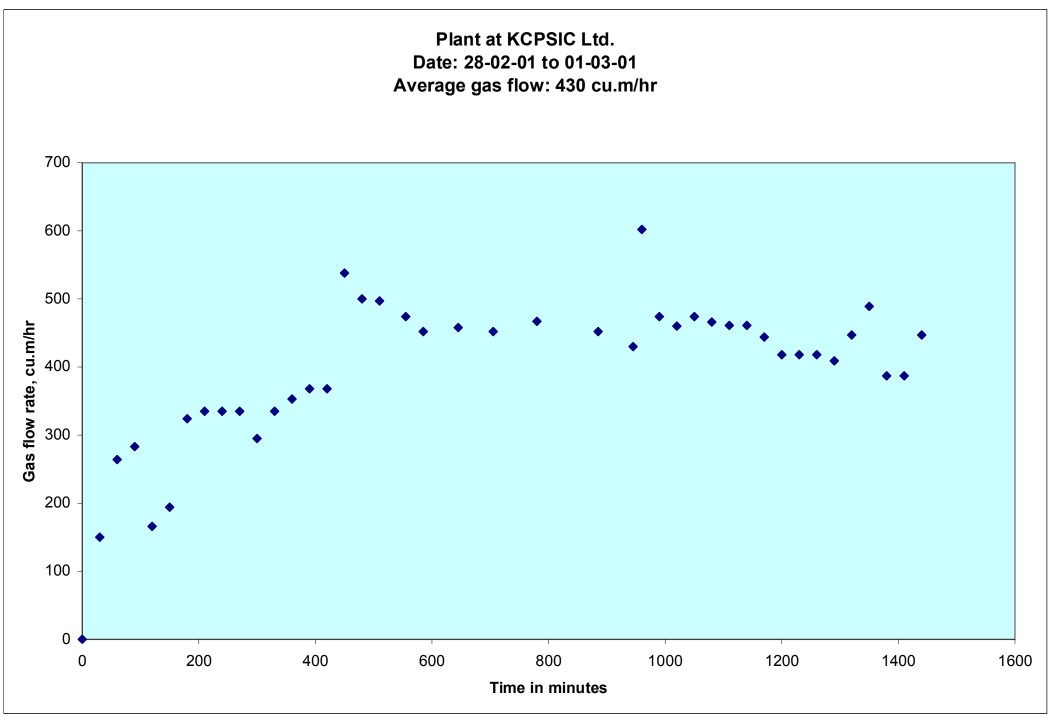
VISHTEC, Melvisharam, Ranipet, Tamil Nadu

A smaller system to handle biogas generated from effluent arising due to leather tanning fleshing is designed and commissioned for a common treatment plant at Melvisharam, Ranipet. The power generated in the duel fuel engine is used in house.

1. Designed biogas handling capacity:	13.5 m^3/hr
2. Designed power generation capacity:	30 kWe
3. Designed H_2S inlet concentration:	3.0 %
4. Measured H_2S inlet concentration:	2.5 – 3.0 %
5. Type of Engine used:	Dual fuel
6. Commissioned:	June 1999, running on an average of 4 hrs each day.



Performance of the hydrogen sulphide scrubbing system at average gas flow rate of 430 m^3/hr



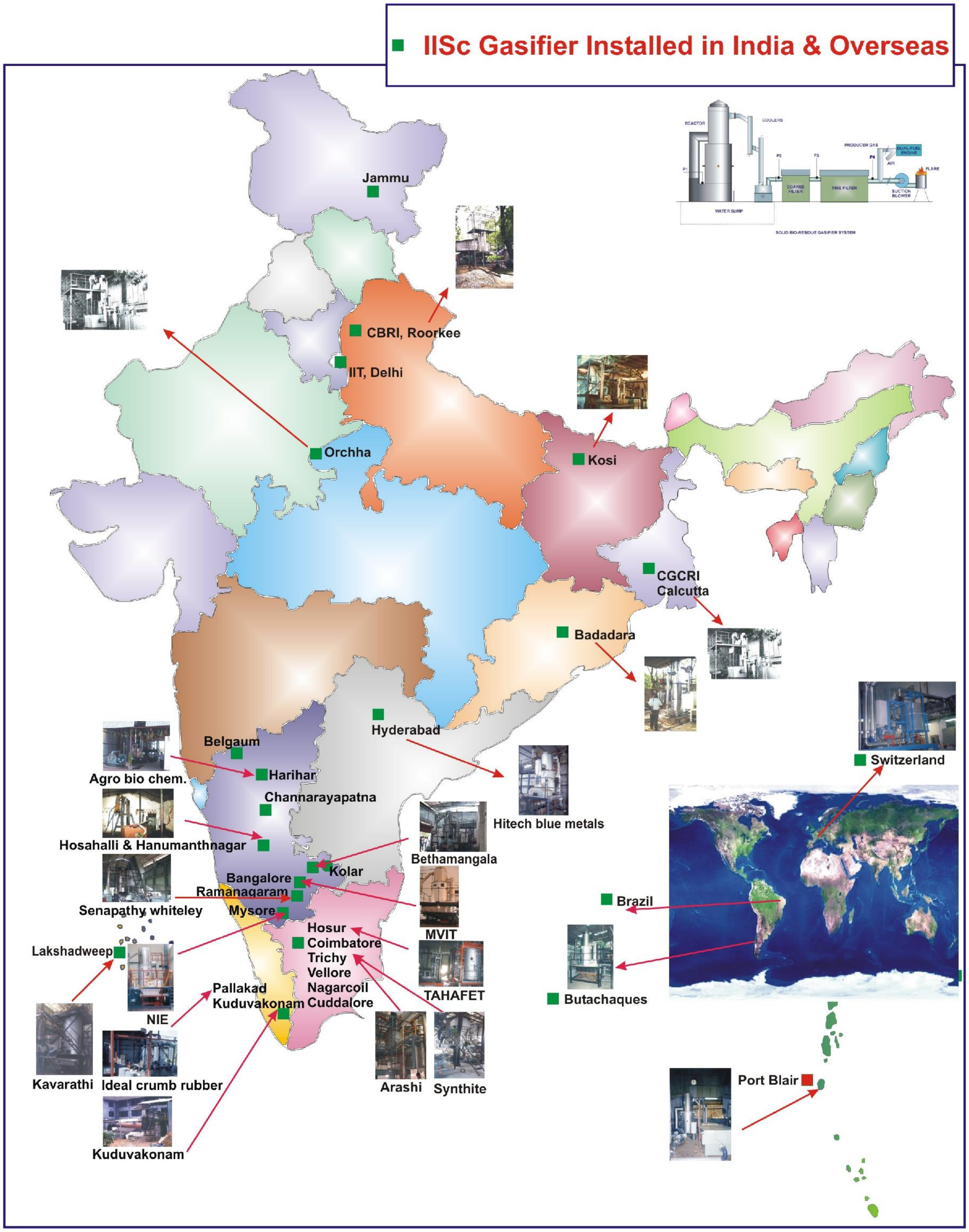
Typical plant loading of Hydrogen sulphide scrubbing system

Picture of Scrubbing Solution & Precipitated Sulphur used in ISET Process

9
Field systems performance

Overall summary

The field systems have been implemented since 1987. In the industrial phase, during 1987-1992 the Ministry of Non-conventional Energy Sources (MNES) established a programme of dissemination of a subsidy based thousand gasifier programme in which water pumping for farming was the primary segment. Towards the end of the programme, 20 kWe gasifier based systems were disseminated through the subsidy approach. These gave the valuable design input from user handling the system and also showed the pathway for future development of high power level systems for industrial applications. In the thousand gasifier programme, about hundred 5 hp rating diesel engine based dual fuel operating systems for individual water pumping applications based on the IISc design were installed. Subsequently, the technology has undergone radical changes based on inputs from the field systems. These changes are in terms of design, construction material and user friendliness of the system. In this era of the new millennium, gasification has evolved as a start-of-the-art technology at IISc and it can compete with best some of the technologies in the world. A wide range of technological packages have been offered to industries and institutions by it and its licensed technology holders in the recent times and are listed as follows.



Glimpse of IISc Based Gasifier Installations in India and Overseas

Summary of the Field Experience

Based on cumulative 18000 hours of operation on the three systems indicated in Table 1, operating costs are estimated. The actual labour involved in the operation has been considered for obtaining the labour costs. The cost towards operation and maintenance are from the investment made by the user and manufacturer over the period of run.

Table 1 Operating cost distribution for thermal systems of different capacities

System location	Application	Hours of operation hr	Gasifier rating kg/hr	O & M Rs/kg/hr	Labour Rs/kg/hr	Total Rs/kg/hr
Ideal Crumb	Thermal	5500	60	0.1	0.15	0.25
Tahafet	Thermal	10500	300	0.14	0.16	0.3
Arasi	Electrical	3000	500	0.08	0.16	0.24

Typical cost of operation and maintenance along with the labour a diesel engine being offered commercially between Rs.0.2 to 0.35 per kWh. This cost excludes the lubricating oil and fuel oil used. Based on this, the cost for power generation is indicated in the Figure 2. Using the cost of O & M on the gasification system as indicating in the Table 1, the overall costs are presented in Figure 2.

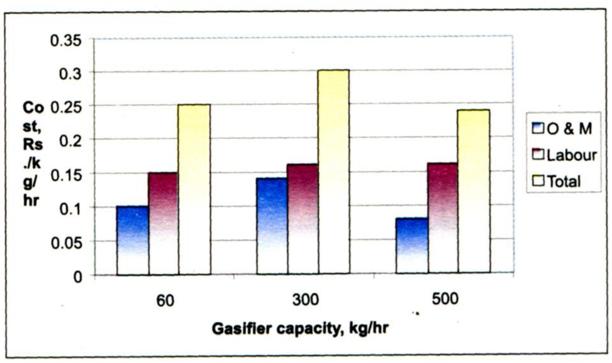


Fig 9.1 Distribution of cost towards O & M and labour for operating a gasifier system

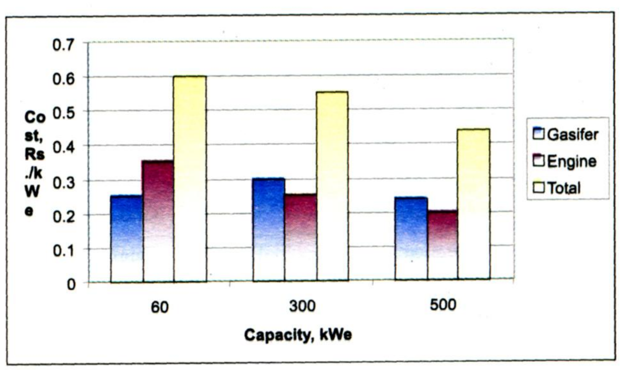


Fig 9.2 Distribution of cost towards O & M and labour for a gasifier and engine system

Village & Rural Electrification Installations

Installation	Rating	Services	YOI	Status
Hosahalli, Kunigal Taluk, Karnataka	20 kWe	Irrigation/Lighting/ Drinking water/flour mill	1995	Functional
Hanmanthnagara, (neighbouring village)	20 kWe	Lighting/Drinking water/ flour mill	1996	Functional
Ungra, Karnataka	20 kWe	Irrigation	1993	Project closed
Vilacura, Santiago, Chile	50 kWe	Electricity supply via Grid	1998	Functional
Deewan Estate Bethamangala, Karnataka	35 kWe	Irrigation/Illumination	2000	Functional

YOI: Year Of Installation; Functional

Industrial Thermal Installations

Installation	Rating	Application	YOI	Status
Synthite Industrial Chemical Ltd, Coimbatore	500kg/hr	Marigold flower drying	2000	Functional
Agro Bio Chem. (Pvt) Ltd, Harihar	500kg/hr	Marigold flower drying	2000	Functional
Tahafet, Hosur-635126, Tamil Nadu	300 kg/hr	Heat Treatment	2001	Functional
Comorin Polymers and Plantations Ltd, Kanyakumari Dist, Tamilnadu	70kg/hr	Rubber drying	2002	Functional
Ideal Crumb Rubber Factory, Pallakad, Kerala	70 kg/hr	Rubber drying	2002	Functional
Hi-tech Blue metal powder alloy Ltd., Hyderabad	75kg/hr	Metallurgical	2000	Functional

Industrial Power Generation Installations

Installation	Rating	Application	YOI	Status
Arashi Hi-Tech Bio Power Pvt. Ltd, Coimbatore, Tamil Nadu	1 Mwe	Grid Linked	2002	Functional
Senapathy Whitely (Pvt.) Ltd., Ramanagaram, Karnataka	500 kWe	Captive	1998	To be re-operationalized
Ideal Crumb Rubber Factory Mannarghat, Pallakad, Kerala	100 kWe	Captive	2002	Functional
Electricity Department Andaman and Nicobar Islands	80 kWe	Captive	1990	Operated occasionally
Department of Electricity, Kavarathi, Lakshadweep Islands	300 kWe	Grid Linked	2003	Functional
Dev Power Corporation	120 kWe	Captive	2001	To be re-

Hosur, Tamil nadu				operationalized
Orchha, Tikamgarh, M.P.	100 kWe	Captive	1996	Functional
GB Engineering, Trichy, Tamil Nadu	100 kWe	Captive	2002	Functional
GB Foods, Trichy, Tamil Nadu	100 kWe	Captive	2002	Functional
Vellore Institute of Technology, Vellore, Tamil Nadu	100 kWe	Captive	2003	Functional
Sir M Visveswaraya Institute of Technology, Yelahanka, Bangalore	2 x 120 kWe	Captive	2002	Functional
BAMUL Milk Chilling Unit Anekal, Karnataka	75 kWe	Captive	2003	Tests completed
Varalakonda, Kolar, Karnataka	50 kWe	Captive	2003	Functional

R&D / Other Installations

Installation	Rating	Application	YOI	Status
CBRI, Fire Research Laboratory, Roorkee	200 kg/hr	Thermal - kiln	1998	Functional
XYLOWATT S.A, Chatel-st-Denis	75 kWe	Power	2001	Functional
IIT, New Delhi	20 kWe	Power	1999	Occasionally run
Desi Power, Baharbari Araria District, Bihar	50 kWe	Power	2001	Functional

YOI: Year of installation

Educational Institution Installations

Installation	Rating	Application	YOI	Status
Gogte Institute of Technology, Belguam	75 kWe	Power	2002	Functional
National Institute of Engineering, Mysore	75 kWe	Power	2001	Functional
Jawahar Navodaya Vidyalaya, Gollahalli, Tumkur, Karnataka	100 kWe	Power	1998	Being restarted

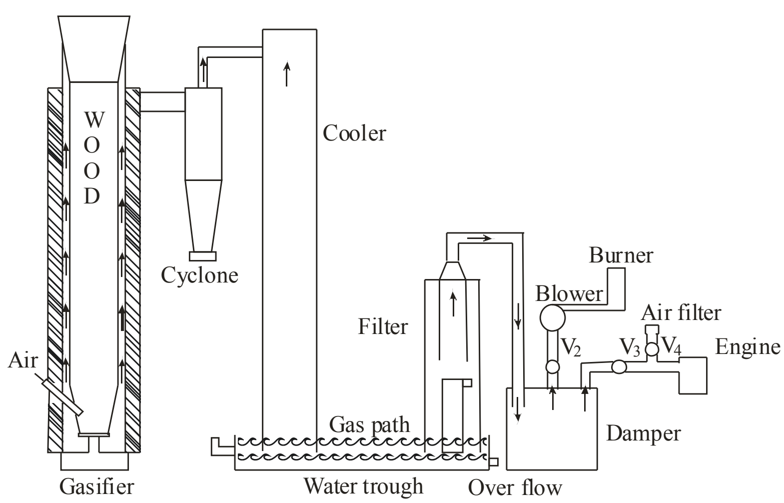
Overall performance of systems

Total number of systems installed :	7
Total thermal :	30
Total electrical :	23
Oil saved :	2700 tonnes (3483 kilo-litres)
Type of biomass used :	Wood, coconut shells, cotton stalks, mulberry stalks etc.
Total biomass used :	13221 tonnes

Village & Rural Electrification Installations

MNES Sponsored Gasification Programme

Field system evaluations started way back in 1987 when 5 hp gasifier based pumping sets (with dual fuel operation diesel generator sets of nominal capacity were installed for water pumping in individual farmer farm. In four years, some 400 systems were built and disseminated in a major MNES 1000 gasifier programme during 1987 – 1992. The system components included a gasifier system and an engine Water pump set as an end use device. Detailed monitoring of the systems was conducted by MNES using third party inspection all over the country (six hundred other systems belonged to other manufacturers in India). The survey showed that the essential concepts that were used in the reactor design were robust from the point of view of gasification efficiency and operational reliability. The systems were used typically for 500 to 600 hours each year because of the agricultural practices. Failure of the reactor shell was noticed around 1200 to 1500 hours of operation. Major limitation on life was traced to the bottom section of the reactor and in some cases failures at the air nozzle section was noticed. The nozzle failure was addressed by adopting an expansion joint. The problem of the reactor life enhancement crept in before the intended developments could take place. These were related to the metallurgical properties of the material in the reactor environment. Even though best of the SS was used, the oxidation and reducing environment at the elevated temperature had significant bearing on the corrosion properties of the material.



Gasifier and the cooling cleaning system

First Version of 3.7 kWe gasifier-engine package

Field visits were made to evaluate the performance and determine if there were any problems related to design. It was noted that the daily use was limited to 5-8 hours of water pumping the first known fact was conservation of diesel, which indicated that instead of 1 litre lasting just one hour, it would last for four hours. This implied 75% diesel replacement.

The common complaint, in earlier visits, was that wood chips were to be made to small sizes and that this was time consuming and for some people, expensive. Some of the users had used locally available biomass like corncobs and Arecanut husk. Here again, the issue was that the dust accumulated in the filters and was noticed after the operation of a day or two. Some claimed that they were producing stones from the gasifier! This was traced to the presence of mud and perhaps some organic matter like white-ant-hill in jungle wood used as fuel. The presence of the fluxing agents in the mud was inferred to be the cause of ash fusion and the formation of “stones”. A special experiment was conducted in which char and clean wood pieces were loaded to demonstrate non-stone producing operation late into the night during one of the visits

During this period, it was decided to take up field projects that have substantive societal significance. The first project conceived was to electrify a hamlet/village that remained un-electrified at that time. After interactions with the Karnataka Electricity Board (KPTCL now), one hamlet called Hosahalli in Kunigal taluk, Tumkur district, Karanataka became available. 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.

Hosahalli

A hamlet, 130 kms from Bangalore, that had 43 families with about 200 inhabitants, 95% of whom were illiterate, had remained un-electrified 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 of 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. Subsequently, a flourmill 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, leading to societal problems. 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 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.

Gasifier Plant (Left) supporting Flour Milling Activity (Right) at Hosahalli

Issues / problems faced and resolved

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 is still on, as it has not reached stability yet. This is only because the true magnitude of local demands has to be assessed.

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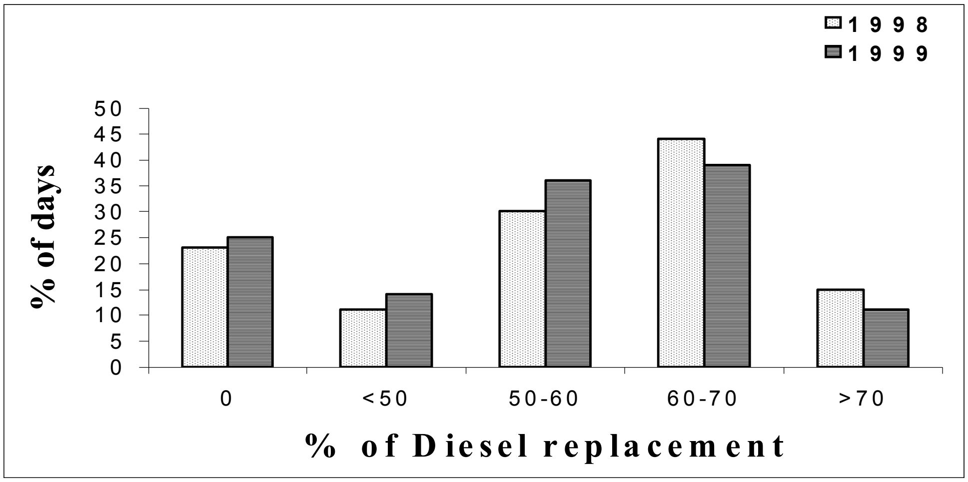
<td>
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<td>% No. days vs. Diesel replacement</td>
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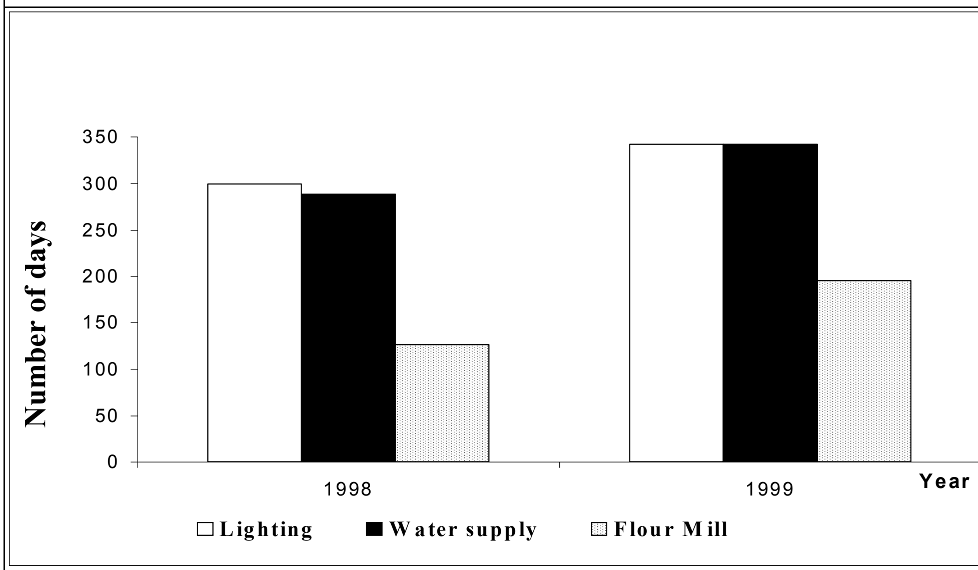
<td>
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<td>Type & No. of days services offered in a Year</td>
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Performance

Current status

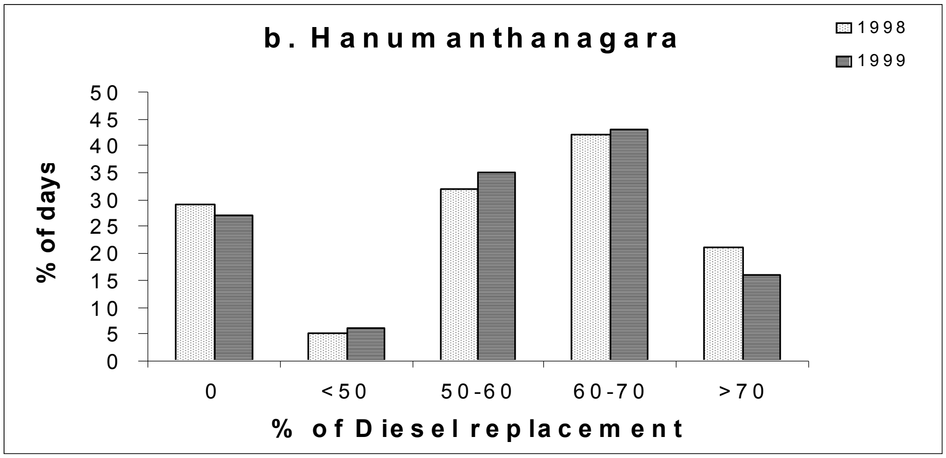
The system is being operation 5-6 hours per day, providing services such as drinking water, illumination, flour mill and irrigational water. The power plant has so far completed nearly 6000 hours and generated about 62,000 units of electricity in the last four years of operation. Of the 6000 hours operation, dual-mode of operations accounts to nearly 75%. Currently the day-to-day operations are being managed by the Gram Panchayat, with the plant being operated by the local village boys.

Hanumanthnagara

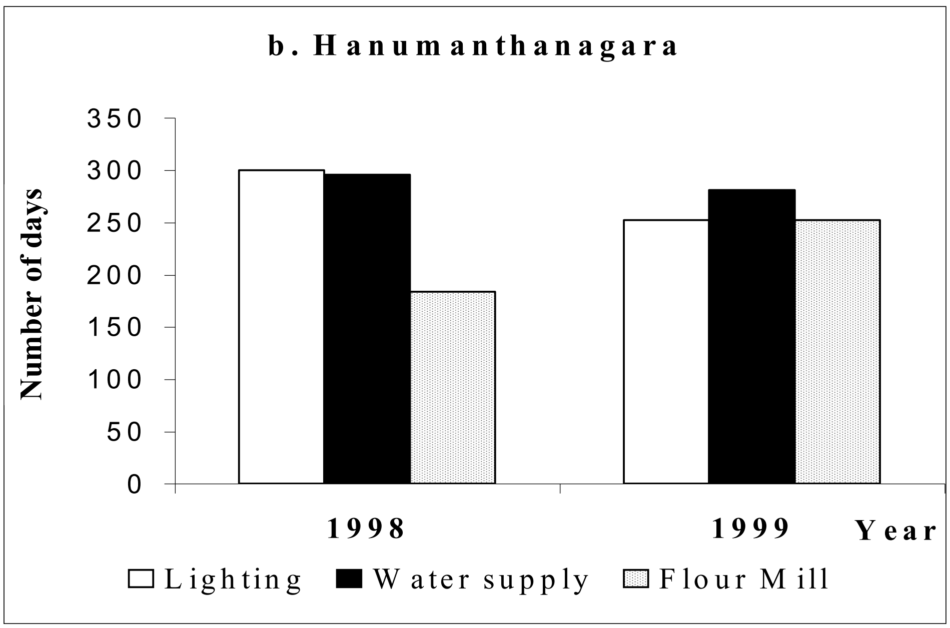
A village, 4 km from Hosahalli, with 50 houses and 250 people on the bank of the Shimsha river (flowing at a lower level) receiving grid electricity wished to have services similar to Hosahalli, essentially since grid electricity was poor. This project was designed using experience gained at Hosahalli. A 20 kWe gasifier-based DG set was installed in 1996. System performance is 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.

	**Gasifier Plant at Hanumanthnagara**

Performance



% No. days vs diesel replacement



Type and Number of Days Services Offered in a Year

Current status

The system is being operation 5-6 hours per day, providing services such as drinking water, illumination, and flour mill. The system has so far completed 4500 hours and generated about 27,000 units of electricity in the last five years of operation. Of the 4500 hours operation, dual-mode of operations accounts to nearly 70%. The day-to-day operations are being handled by the local village boys with entire project operations is being subsidised.

Palarayanahalli, Ungra

This village is 10 km from hosahalli and 110 km from Bangalore. This project was established at the extension of the centre for application of science and technology for rural areas. This project began in 1993.

While the Hosahalli project was being carried out, support was sought to try out the aspects related to irrigation water supply as an operationally sustainable mode of operation. This project was established at the extension centre of the Centre for Application of Science & Technology for Rural Areas — ASTRA located at Ungra — ten km from Hosahalli and 110 km from Bangalore. The project envisaged a two-year operation and began in 1993. A 1.6 km pipeline was laid between the water supply point close to the buildings of Ungra Centre and through the agricultural fields of the twenty-three landowners of the village called Palarayanahalli. At each of the agricultural plots, there was a pipe outlet with a cap. And only one cap would be opened at a time during the operation. Water was pumped sequentially for as long as was required — typically two to three hours per plot. The system installed was an earlier generation 20 kg/hr gasification system with a DG set providing electricity to two deep borewells. The farmers grew mulberry plantation over half an acre each. In specific instances, one-acre plot was also irrigated. In two seasons, during which the system was operated, it was found that the farmers who drew water and paid for it at Rs. 300/- per irrigation per acre, received about three times the revenue they would have got from the land under circumstances where they depended on rain for growing a dry crop like Ragi. Typical annual revenues reported were Rs. 20,000 to 25,000 per year compared to Rs. 7000 to 8000/- per year in earlier times.

Issues/Problems

The total revenues to the operations were barely adequate to meet the operational expenses. There were two reasons for this. (a) The number of users was limited. It was eight to nine in the early stages and later dropped to two; implying man power cost being high. (b) The cost of power generation was high (Rs. 3.50 to Rs. 3.75) and affected by the diesel cost even at 75% diesel replacement. If the power could be generated without diesel, the cost of generation would be between Rs. 2.0 to Rs. 2.50 and would provide adequate margin from the revenues of the sale of water to cover all the running expenditure. The message of this experiment was that it is better to sell water with reliability than generate electricity and supply. People's perception of water as a saleable commodity can be made use of to construct economically sustainable energy packages in the agrarian community, particularly for the marginal farmers whose capital investment ability (for submersible pumps and diesel electricity on an individual basis) is very low.

Butachaques Island, Chile

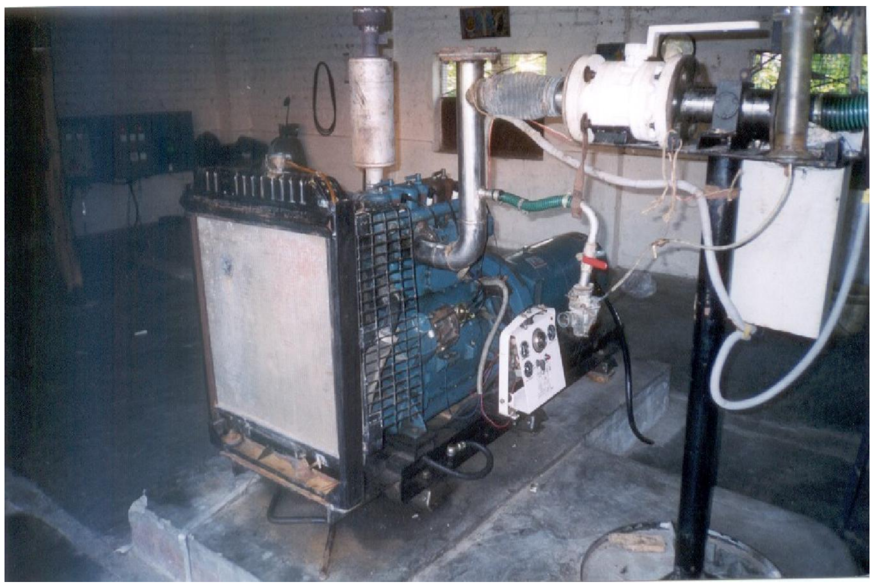
The plant is meant for electrification of a village called Metahue located on the island of Butachauques, South Chile. This was joint project executed by IISc and UNDP-Chile. The total number of houses was 90 with a population of 900, all Spanish speaking, employed mostly in agriculture, aquaculture, particularly on Solomon fish farms; the village has a health centre, community hall and a government school. Most people have individual gasoline driven DG sets or batteries charged once in a while. Use of electricity is mostly for illumination, TV sets; while cooking is done by using bottled gas and firewood. Approximate expenditure per family during winter on electrical energy is 70 US$. A 2 x 25 kVA DG set system was electrically synchronised and fed into the grid at 8 kV and reduced to 220V using a step-down transformer at the user end. The unit comprises of a reactor, gas cooling and cleaning system – with sand filters, D-G sets, biomass processor, drier and a synchronising control panel. Twenty-six houses were electrified and permitted to use electricity for illumination with fluorescent lamps, refrigerator, washing machines and water pumps. The peak-load was determined to be 10 kWe and the electric supply was used for five hours a day to be extended to about eight hours in winter. The measured diesel replacement over a five-hour cycle was 82%. Fuel wood consumed per kWh electricity generated is 1.0 kg. The operation, distribution and tariff collection is with the village cooperative. Current tariff estimate is set at 40$ per house/month.

Performance & Current Status

The measured diesel replacement over a five-hour cycle was 82%. Fuel wood consumed per kWh electricity generated is 1.0 kg. The system has clocked in excess of 2500 hrs of operation and has generated about 60,000 units till March 2001. Based on the latest information obtained through e-mail, the plant has been operating with diesel due to shortage of firewood, but the reason for this to happen is not evident.

Dewan Estate, Kolar

A farm estate located 80 km from Bangalore in Kolar district is owned by a church father, Father Jovita. A 50 kg/hr gasifier has been installed to supply gas to one diesel engine of 20 kWe and another a 100% producer gas engine of 16 kWe capacity. The system comprises of a reactor, gas cooling and cleaning system – with sand filters and engine-generator sets. The system has been operating since August 2000 and has clocked in excess of 2100 hours. The power generated caters to irrigational water pump sets and illumination of staff quarters. The system is operated when ever in need of irrigational water, typically for 3-4 hours per day.



A 100% producer gas engine at Dewan Estate

Performance and Status

The plant has been manufactured and installed by M/s Netpro Renewable Energy (India) Limited, Bangalore. The diesel-generator set is normally utilized for the gasifier start-up and once the combustible gas is generated, the gas engine is started and diesel-generator shut-off. Both the engines have been a cumulative operating hours of about 3100 hours, of which the gas engine has operated for nearly 1400 hours. The number of units generated is about 38,000 units of which nearly 55% is generated using 100% gas engine.

Industrial Thermal Installations

Fossil fuels have become primary source of energy to meet the thermal requirements of both small and large industries. The number of small-scale industries that uses liquid fuels in the range of 100 lt/hr is quite large. This requirement has led to the development of efficient combustion devices that could meet both efficiency and emissions norms. Over the years, many of the solid fuel based combustion devices have been converted to petroleum-based fuels mainly due to its availability, compactness and ease of operation; without serious concern on the economics of operation. Industries have adopted petroleum-based fuels for various applications, apart from electricity generation via internal combustion engines. Some of these applications are the low temperature ones like, drying of various food and non-food items, hot air for specific process requirements, etc., while the high temperature are for boilers - steam generation, thermic fluid heaters – for process heat, furnaces in heat treatment industries, steel processing, ceramic sector, etc. These applications have led to increased consumption of petroleum fuels, which other wise could have addressed only the transport sector. With the increase in cost of petroleum fuels, the overall economics are considerably affected since energy forms a substantial part of the product cost. Economics and environmental considerations are the driving forces behind the search for alternate sources of energy. Producer gas generated can be used for meeting the thermal energy needs in an industry. Temperature requirements in the range of 50 to about 1000° C can be addressed using a gasifier system. A few of such industries where gasification technology has been adopted in the recent times are briefly discussed.

Synthite Industrial Chemicals Ltd, Karamadai

Synthite Industrial Chemicals Ltd, is a group company, dedicated towards chemicals from agricultural and horticultural crops. They have established a network of farmers, with whom they have arrangement to grow and procure the flower. This industry is turning out to be like the sugar industry to protect the input raw material by establishing direct contact with the people growing it. The company processes about 35,000 to 40,000 tons of marigold flowers annually at Karamadai plant located near Coimbatore, Tamilnadu. The industry processes flowers for fragrance and carries out major extraction from marigold flowers to produce an oleoresin leading to chemical called Xanthophyll. The process is energy-intensive in terms of drying. The industry has a capacity to dry about 800 to 900 kg/hr of marigold flower using fluidised bed driers. One of their drier is powered with a 500 kg/hr capacity gasifier and the system has completed about two years of operations.

The Gasifier Plant

The 500 kg/hr gasifier system saves about 140 lt/hr of diesel, generating about 2 MWth thermal power equivalent hot gases at 100 $\pm$ 5^{0}C. The key elements of the system are a reactor, gas cooling and cleaning system. The producer gas is combusted using a specially designed burner and then diluted with ambient air in order to attain the required temperature of 100 $\pm$ 5^{0}C. The hot gas is then passed through the fluidised bed drier, meant for drying marigold flowers. The system is configured with a PLC to carry out operations related to ash extraction, fuel feeding and other safety regulatory measures for the system. All the data with respect to pressure and temperature are logged continuously on to a computer.

Issues/Problems Resolved

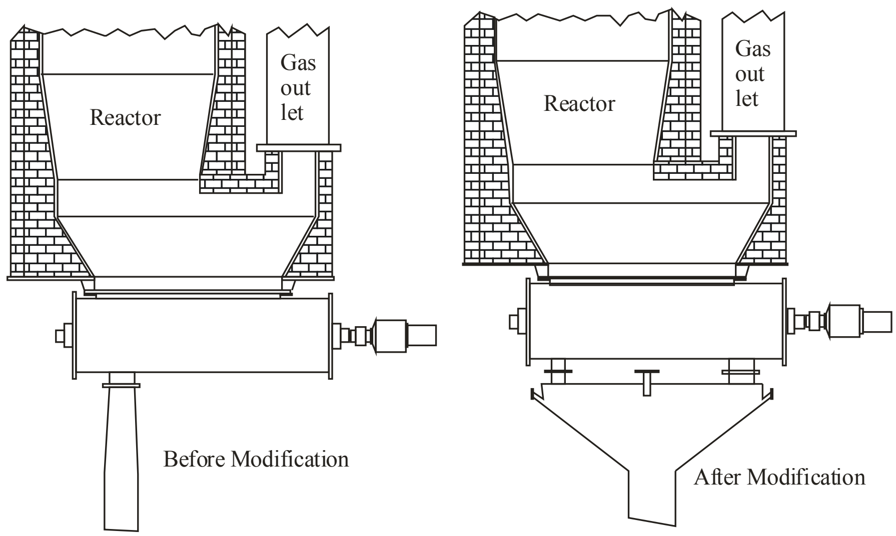
The project was mainly conceived to operate on marigold flower waste briquettes; therefore for the initial trials marigold briquettes were outsourced. Initial trials at SICL were conducted using outsourced marigold waste briquettes as the fuel. There were problems related to ash fusion, which was not anticipated initially. Marigold waste has an ash content of 5-6%, which is well with in the specified limit of 8% ash that could be handled by the reactor. However, it turned out that the briquettes had ash content averaging around 15% with a peak value in excess of 25%. The high ash content resulted on the account of contamination with extraneous material like sand/mud during the course of briquette manufacture. Even though the gasification process was not affected, the throughput was definitely reduced. This called for an unscheduled plant shutdown after 150 hours of operation. The reactor unloading showed presence of large mound of fused material inside the reactor, below the air nozzles leading to choking and reduced throughput. Upon analyzing it became clear that during 150 hours of operation about 65 tons of briquettes were used resulting in generation of 10 tons of ash (~15%). However, the ash was extracted during gasifier operations at a rate amounting to 8-10% ash, the excess inorganic left over in the reactor resulted in a fused mass over the period of time.

Since it was problematic to restrict ash content in the marigold waste briquette on account of briquette manufacture procedure, alternate feedstock were explored until briquettes of right quality is produced or procured. Coconut shells came as an immediate rescue both in terms of availability and pricing. All subsequent operations are carried using broken coconut shells. The issues addressed were important from the point of enhancing the reliability of the plant and are as follows

- The gas quality was improved by employing a hot gas cyclone and a redesigned gas scrubbing system. The outcome of this exercise was a clean gas with particulate and tar concentration less than 50 mg/m^3.

- The issue related to air nozzles was the puncturing of outer water jacket leading to water ingress into the reactor. The usage of hard water resulted in scaling in the water passage providing insufficient cooling followed by rupture. This occurrence not only increased the maintenance cost but also posed operational problems with respect to increased pressure drop across the reactor. This issue was temporarily resolved by resorting to soft water; subsequent to which the water-cooled nozzles were replaced with high alumina ceramic nozzles.

- The motorized screw based ash extraction system has been newly adapted to deal with reasonably high ash content fuels. This design does not have a grate and the entire fuel charge is supported on the screw, which is rotated to remove the ash/residue at periodic time intervals. The operation of the screw is a function of feed (% ash content) and as a consequence the pressure drop encountered at the reactor exit. In the initial design as shown in the Figure below, it was envisaged that one outlet at the screw bottom is sufficient to extract the residue at the pre-determined rate. Though, this operation was satisfactorily, it was found that the gas exit side of the reactor was getting filled with char; resulting in the increase of reactor pressure drop. This increase in pressure drop has direct effect on the gas throughput and there by the temperature in the drier. This problem was resolved by providing additional outlet in line with the gas exit. The gas exit zone being in the screw-operating regime providing additional outlet was found to be effective in tackling the pressure drop issue.

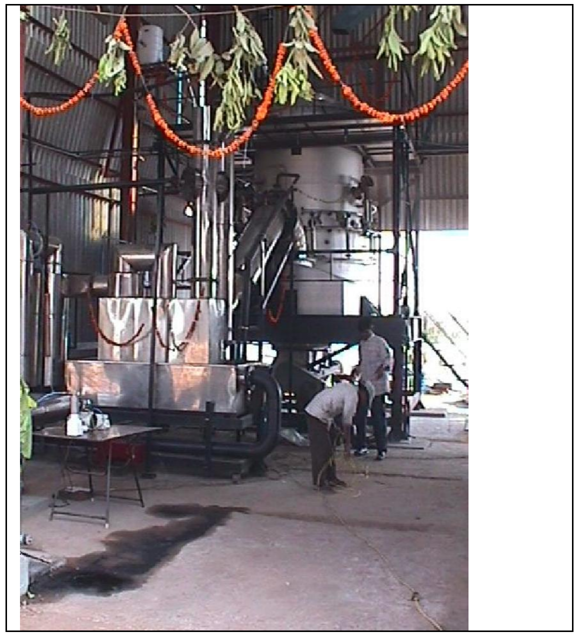


Performance & Status

The plant has been manufactured and installed by M/s Netpro, Bangalore. Upon successful demonstration, the industry has received financial assistance from MNES, Govt. of India. The system has so far completed about 4500 hours of operation saving about 600 kilo liters of diesel since its commissioning in July 2000. The system is normally operated during marigold flowering season, which is typically 6-7 months (October – March) in a year.

Agro bio chem. Pvt. Ltd, Harihar

Agro Bio Chem. Pvt Ltd is another company, which carries out major extraction from marigold flowers to produce an oleoresin leading to chemical called Xanthophyll. The factory is located In Telagi village 18 kms from Harihar. The industry has the capacity to dry about 500 to 650kgs of marigold flower during the season. Two of their fluidised bed driers are coupled to two gasifiers of 250 and 500 kg/hr capacity. Of the two gasifiers, 250 kg/hr has been functioning since 1998, whereas the 500 kg/hr system has been functioning since 2002. The 500 kg/hr plant comprises of PLC operated gasifier system including a fuel feed sub-system and a zero discharge water treatment plant.



The Gasifier Plant

The overall plant configuration is similar to the Synthite Industrial Chemicals Ltd (SICL) system, in addition the plant is provided with a full-fledged water treatment plant for the treatment of recycled water.

Issued/Problems Resolved

This particular system faced fewer problems with respect to plant operations since the system was adequately modified based on experiences from the SICL system. But the major gain from this plant is the introduction of ceramic nozzle (99% Alumina) in place of originally planned water-cooled nozzle. Water -cooled nozzle failed to perform even upon using soft water resulting in water seepage into the reactor and damaging the ceramic lining by quenching under hot condition.

Another area that received more attention is the water treatment plant. Even though the treatment circuit functioned satisfactorily in terms on overall performance, the amount of clean water required for reverse washing the sand bed is large enough other than causing problems in disposal of large quantity of sludge. It has been found by laboratory scale experiments that cost effective solution exists by adapting certain flocculants. Flocculation helps in removal of particulates, mostly in sludge form without loosing much water and some dissolved organics. This is being currently being implemented at the site.

Performance and status

The 500 kg/hr plant has been manufactured and installed by M/s Netpro, Bangalore. Upon successful demonstration, the industry has received financial assistance from MNES, Govt. of India. The 250 kg/hr system has so far completed about 13000 hours of operation saving about 1040 klt of diesel since its commissioning in 1998. Similarly the 500 kg/hr has completed about 4100 hours of operation saving about 550 kiloliters of diesel. The system is normally operated during marigold flowering season, which is typically 6-7 months (October – March) in a year. Recently the industry has received financial incentive from Govt. of Finland for accruing carbon credits from CO_2 emissions savings.

TAHAFET, Hosur

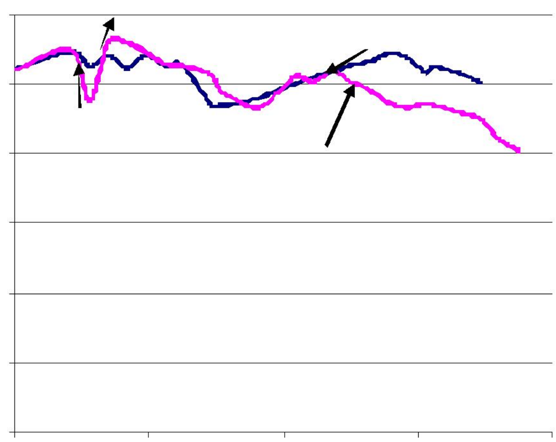
TAHAFET (High temperature application at Tamilnadu Heat Treaters and Fettling and Services Pvt Ltd) located in Hosur, Tamilnadu is involved in providing heat treatment services to a number of automotive based industries. The requirement of high temperature for a heat treatment application in the temperature range of 600 to 920^{0}C was being met by diesel/LDO till the gasifier was introduced in 2001. A 300 kg/hr gasifier supplies producer gas to eight heat treatment furnaces meant for normalising and tempering operations.

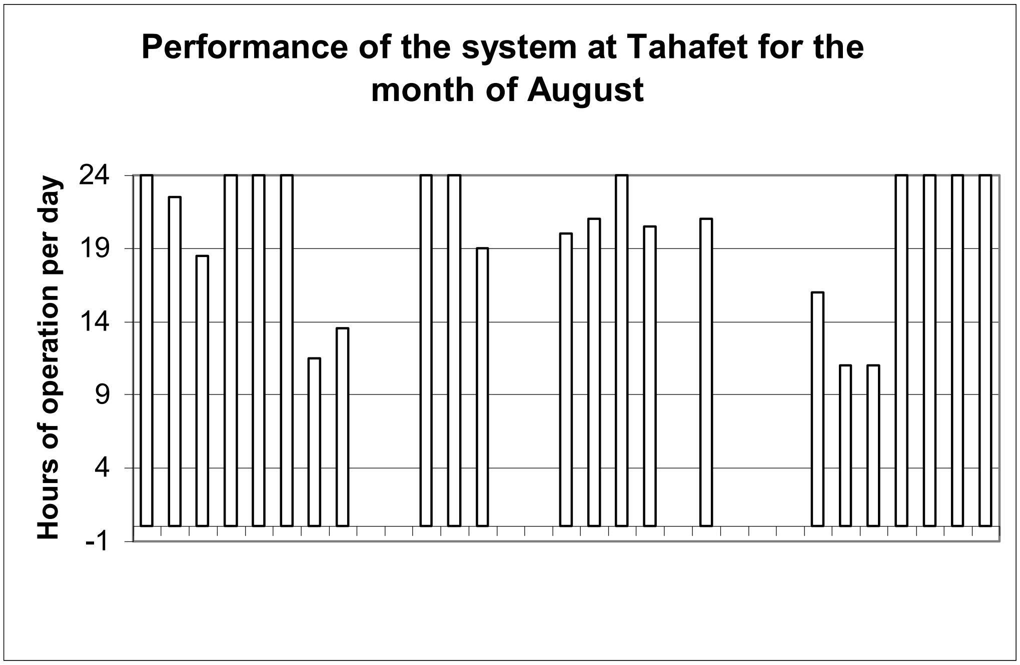
The Gasifier Plant

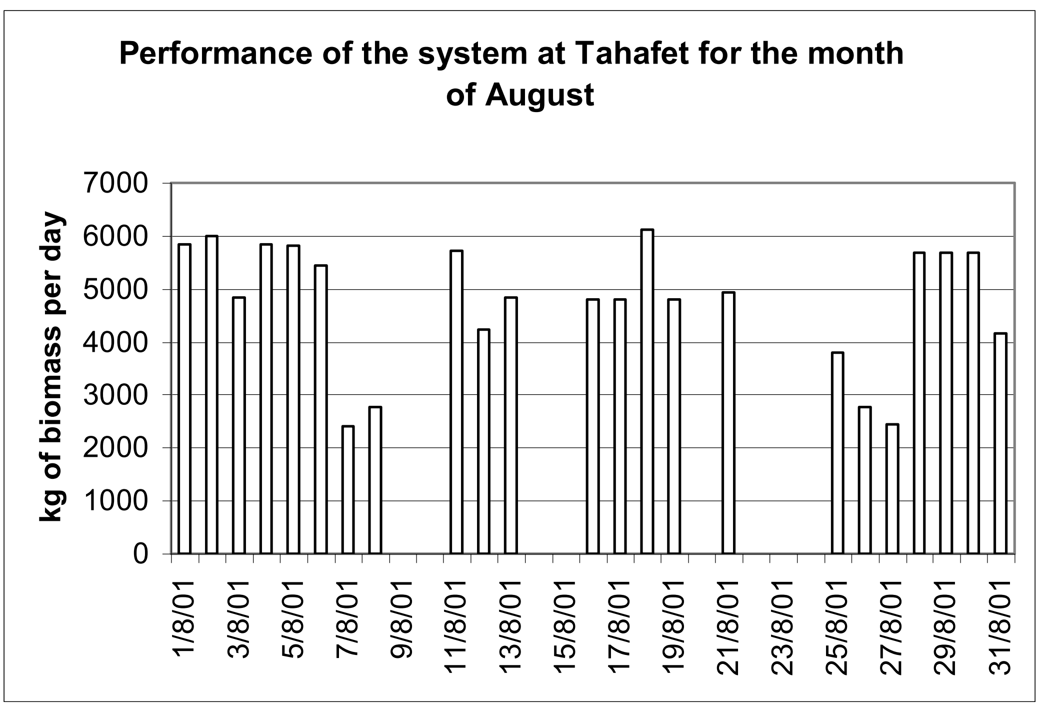
The overall plant configuration is similar to the Synthite Industrial Chemicals Ltd (SICL) system, in addition the plant is provided with a full-fledged water treatment plant for the treatment of recycled water.

Performance and Status

The plant has been manufactured and installed by M/s Energreen Power Ltd, Chennai. Upon successful demonstration, the industry has received a part of financial assistance from MNES, Govt. of India. This particular system faced fewer problems with respect to plant operations since the system was adequately modified based on experiences from the earlier installations. The gasifier system has completed in excess of 10,000 hours of operation, replacing about 2000 litres of fossil fuel every day. This works to cumulative of 800 kiloliters of fossil fuel. Apart from becoming reduced dependent on fossil fuels, it is acknowledged that the quality of the end of product after heat treatment has substantially improved due to higher combustion efficiency with producer gas. It is legitimate to bring out here as to how the nature of fuel affects the quality of the end product. The liquid fuel system is designed to operate with excess air in order to ensure complete combustion. Therefore the excess oxygen present in the flue gas at elevated temperature (~ 600 C and above) resulted in oxidation of the material being heat-treated thus resulting in poor surface finish and weight loss of the end product. The presence of sulphur in the fuel also resulted in eroding the surface other escaping as SO_2.




Performance of the system at Tahafet for the month of August
Hours of operation per day
24
19
14
9
4
-1


Performance of the system at Tahafet for the month of August
kg of biomass per day
7000
6000
5000
4000
3000
2000
1000
0
1/8/01
3/8/01
5/8/01
7/8/01
9/8/01
11/8/01
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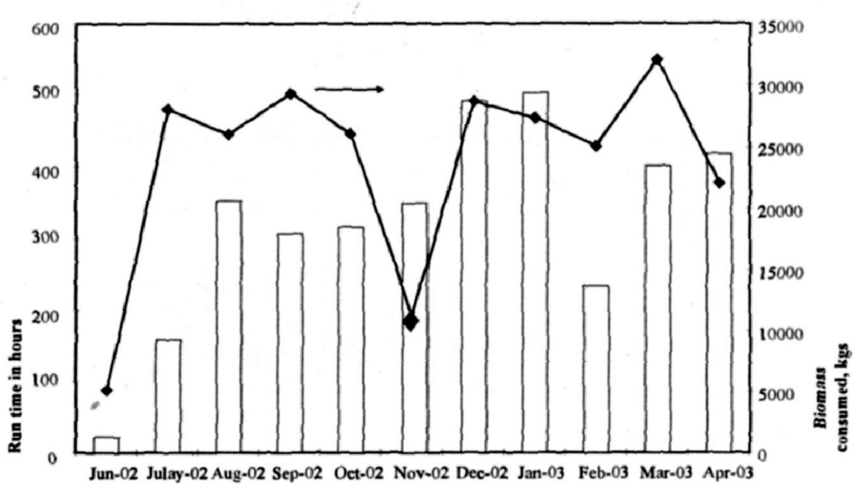
Comorin Polymers and Plantation Ltd, Nagarcoil

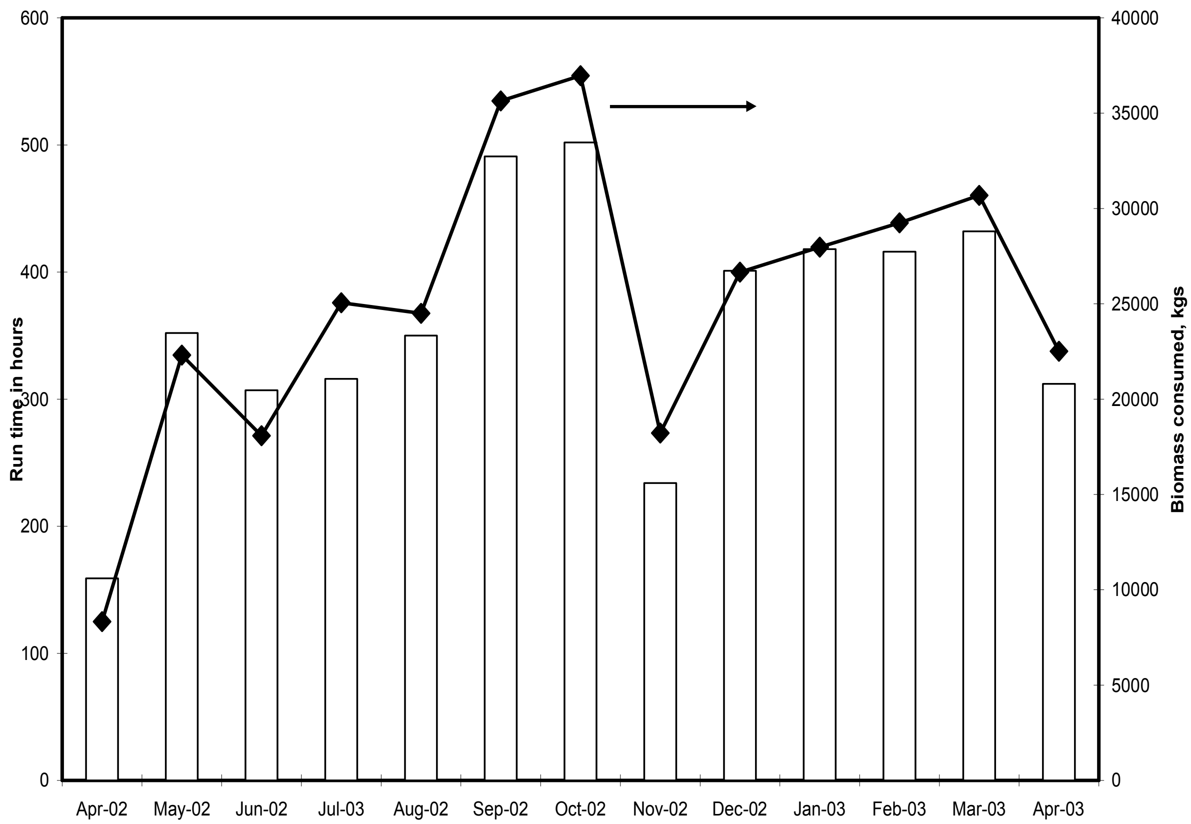
Comorin polymers and plantations ltd, Nagarcoil, Kerala are producers of crumb rubber. The company has substituted the diesel for drying application with producer gas generated from a 90 kg/hr gasifier. The gasifier package comprises of a reactor, gas clean-up system and a burner. They are using a mix of cashew shell and coconut shells for generating gas. The system has completed about 4800 hours of operation since its installation in June 2002, and has resulted in saving of 90-100 kl of HSD. Typical costs involved towards operation and maintenance worked out to about 8% of the initial capital investment, this includes few hardware changes. Major modification undertaken at the field is related to the relining of the bottom part of the reactor with 75% Alumina brick in place of the eroded high alumina tiles at the end of 3200 hours of operation. Other modifications/repairs are related to faulty operations or material defect or replacement of the ceramic air nozzles (every 600 hours). This plant has been manufactured and installed by M/s BETEL, Bangalore. Upon successful demonstration, the industry has received financial assistance from Rubber Board, Govt. of India.



Summary of gasifier performance in one year of operation

Ideal Crumb Rubber, Palakkad

The ideal crumb rubber factory at Palakkad, Kerala is involved in the manufacturing of crumb rubber by treating waste rubber and converting it into rubber blocks for further usage. The industry was using diesel for drying of rubber at 103^{o} C. This is totally replaced with producer gas generated from a 90 kg/hr gasifier in the month of March 2002. The system configuration is ever much similar to the Nagarcoil system. Similarly there was another gasifier installed for power generation application for captive use. So far the thermal system has clocked about 4900 hours of operation and has saved diesel to the tune of 100 kl. This particular system has incurred maintenance expenditure to the tune of 9% of the initial investment cost during its first year of operation. These are related to replacement of the ceramic air nozzles (every 600 hours), modifications in the cyclone and improvements in the cooling system. This plant has been manufactured and installed by M/s BETEL, Bangalore. Upon successful demonstration, the industry has received financial assistance from Rubber Board, Govt. of India.



Summary of gasifier performance in one year of operation

Industrial Power Generation Installations

Senapathy Whiteley Pvt Ltd, Ramanagaram

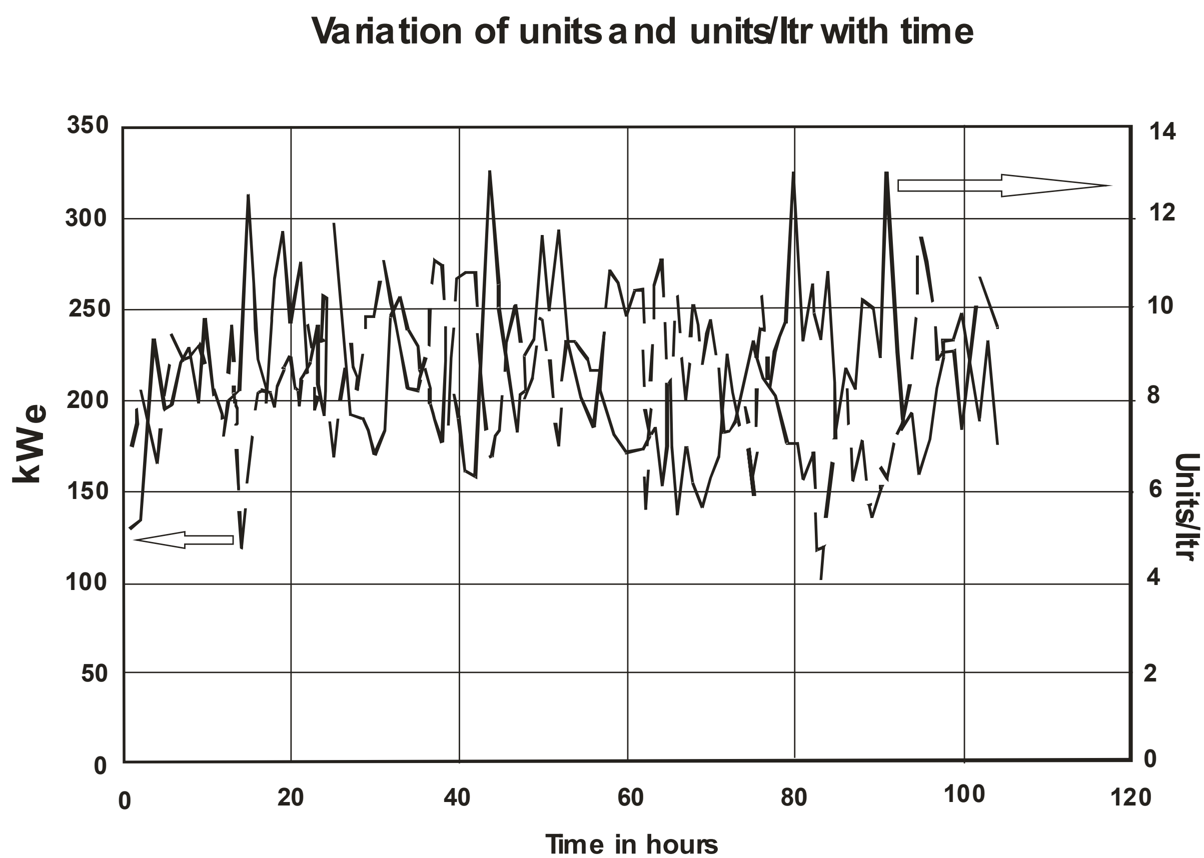
Senapathy Whiteley Pvt. Ltd, Ramanagaram is located on the outskirts of Bangalore city (~40 km) admits thick mulberry and sugarcane cultivation region. It is an ISO 9000 certified company involved in the manufacture of electrical insulation boards, filter grade paper and allied products, intended mainly for export. According to the 1996-97 financial year, their captive diesel-generator sets met about 44% of their electricity requirements mainly due to poor availability of grid electricity thus resulting in large expenditure on diesel fuel. Therefore a 500 kg/hr gasifier system was installed to operate their existing diesel-generator sets (2 x 275 kVA) in dual-fuel mode in the month of June 1998. The novel concept of this power plant was to use locally available mulberry stalks as the feed stock and the use of wash water from their paper plant for gas cooling and scrubbing operations. The system operated for about 1000 hours on an intermittent basis and the main reason for this to happen was the non availability of mulberry stalks. During this period, major development took place in terms of design and development of a superior gas clean-up system. The new gas processing aimed at using producer gas in turbocharged engine, involved deployment of a diesel based scrubbing system in order to reduce the particulate and tar level in the gas to less than 25 ppm. Subsequently in the year 2000, the system was upgraded to facilitate operations with multiple feedstocks, which include agro residue briquettes. This up gradation was funded by MNES, Govt. of India, where in screw based ash extraction system and PLC based control system were incorporated. Another reason for including PLC control was from the point of ensuring safe gasifier operation.

It so happened that due to operator's negligence there were three instances of back-fire (flame travel back-ward), while operating in burner mode. These caused minimal hardware damage but seriously affected the morale of the operating personnel. Subsequently by holding discussions and with the clearance of Safety Council, Karnataka chapter confidence in the system was restored. Also additional safety devices in the form of a flame flash back arrestor burner and oxygen measuring instrument were introduced.

Subsequently the system operated for about 400 hours on an intermittent basis and currently the plant is not functional due to management related issues, non-availability of adequate water etc. The current gasifier configuration comprises of a reactor, gas cooling and cleaning system – with sand filters, diesel scrubber, fabric filter, biomass conveyor and a PLC based control system.

Performance and Status

In the 1400 hours of operations, an average diesel replacement of 67-70% has been recorded with peak value being of the order of 80-82%. Higher average diesel replacement was not attained mainly due to fluctuating nature of the electrical loads. The load fluctuation is so significant that the diesel consumed in diesel alone mode produces 2.8 units per litre in comparison to 3.0 units per litre at near constant load. This has posed very tight conditions for dual fuel operation since optimizing the load following capability for high diesel replacement is a difficult task. The measured load fluctuation is as much as 100 to 300 kWe over as short durations as 10 to 20 minutes. This variation of load and number of units obtained per litre of HSD (in dual fuel mode) over a period of 100 hours of continuous operation is shown in the figure below. This fluctuation in load could be one of the worst possible load profile desired from the point of optimising replacement in dual fuel mode of operation and even under these conditions the number of units delivered per litre of HSD is about 10 implying diesel replacements of the order of 67%. The total number of units generated in dual-fuel mode is about 0.15 million units, effecting a diesel saving to the tune of 32 kl. As mentioned earlier, the plant has stopped functioning since August 2002 due to reasons such as low productivity and water shortage; they have however expressed interest to revive the operations once the shortfalls are overcome. This plant has been installed and supported by ABETS, IISc, Bangalore. Upon successful demonstration, the industry has received financial assistance from MNES, Govt. of India.



Variation in load and No. of units/litre of HSD in 100 hours of continuous operation

Arashi Hi-Tech Bio Power Pvt Ltd, Sulthanpet

Arashi Hitech Bio power is an independent power producer (IPP) working with the single largest capacity fixed bed gasifier based power package linked with the grid in the country. It is located in a village known as Sultanpet in Tamilnadu, where there is abundance availability of coconut shells. The power plant was conceived to house 2 x 800 kg/hr gasifier to supply gas to engines operating on dual-fuel and gas alone mode. In the first phase of activity, a 800 kg/hr gasifier system was integrated with a low speed marine diesel engine in July 2002. The power plant was conceived to operate with coconut shells as the feed stock with the intention of extracting value addition product such as activated carbon from coconut char. The recovery of activated carbon was intended to offset the raw material or feed stock and thereby lower the operational cost per unit energy generated. The power plant houses the state-of-the-art technology in terms of gasification system, PLC based automation and control system, full fledged water treatment plant, power package and evacuation systems.

Issues/Problems Resolved

One of the main issues that were addressed in this particular installation is relating to the gas clean-up system elements and the water treatment plant.

- In the installed version, the fabric filters were placed immediately at the exit of the chilled water scrubber. This arrangement resulted into frequent blocking of the fabric filter due to moisture condensation. In the revised arrangement, the fabric filters were placed down stream of the blower, resulting in gas getting reheated on account of compression in the blower. There were also few moisture traps located in the gas ducting at strategic location to condense moisture present in the gas. This rearrangement subsequently resolved the moisture condensation in the fabric filter. The fabric filters are provided as duplex filters, thereby enabling on-line maintenance during gasifier operation. The current experience says that filter requires cleaning in about 100 hours and in some instances lesser.

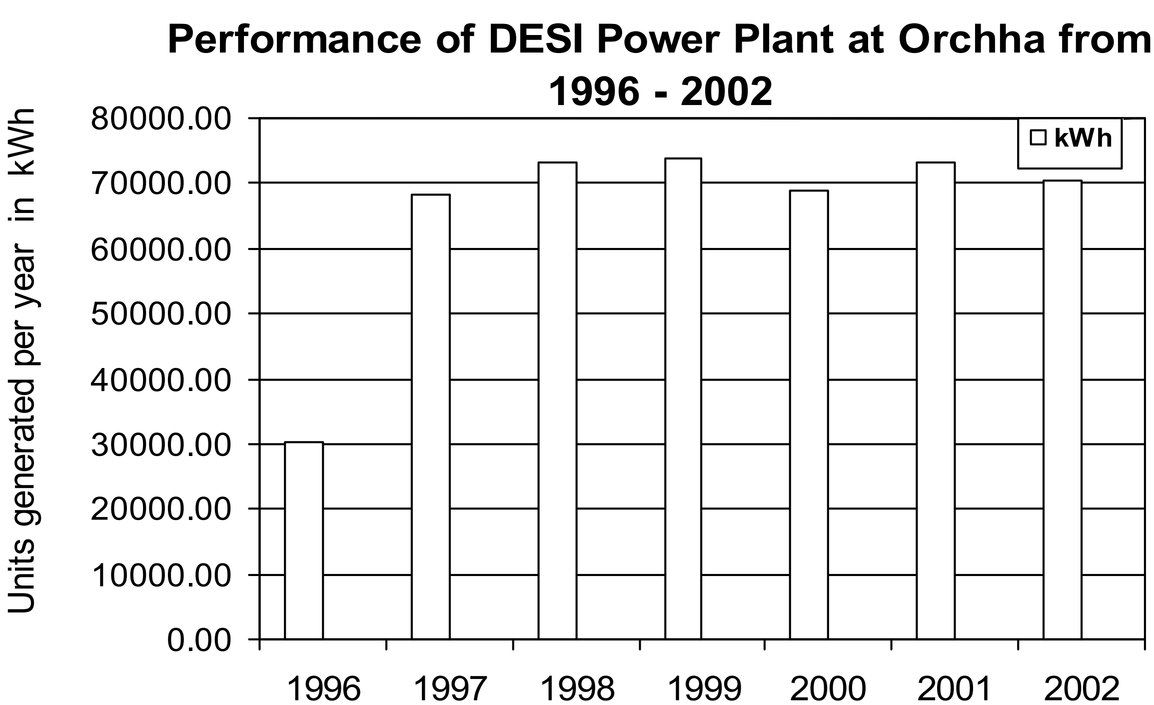
- Identifying the importance of the water treatment plant in the entire plant operation, large amount of attention was paid to firm up its operations. As this being conceived to have flocculation tanks, the dosage of chemicals required and the duration and the number of treatments for each day of operation had to be clearly established. In order establish these procedures a number of small scale experiments in the form of jar tests were conducted and parameters optimised. These actions have led to a virtually zero effluent discharge power plant.

Performance and Status

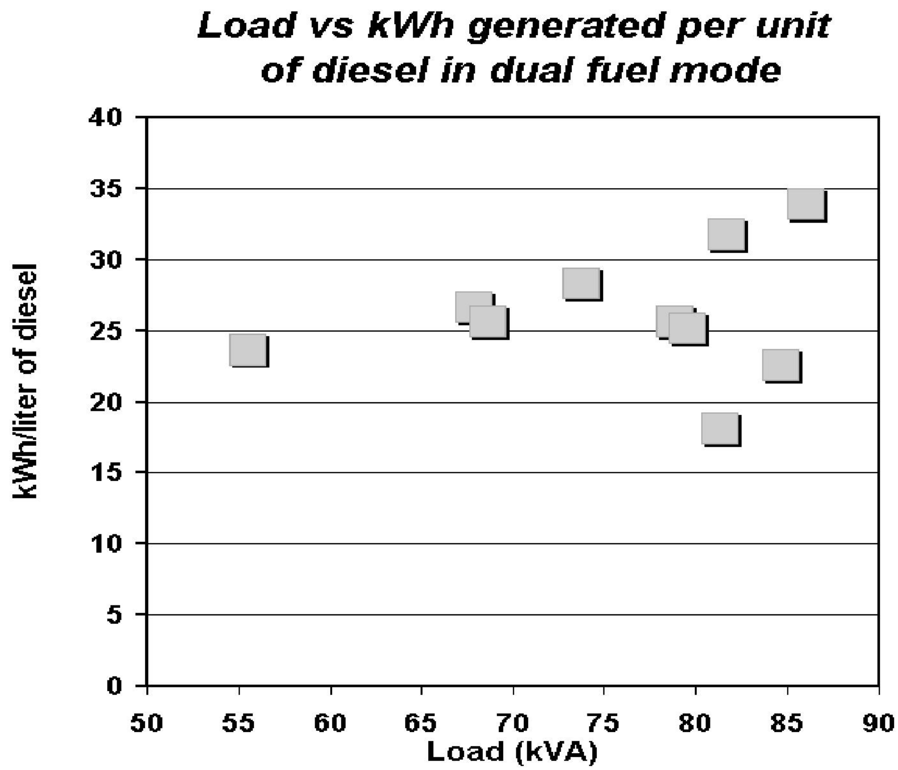
The power plant is operated in a continuous mode at an average load of 600 kWe. The unit commenced exporting electricity to the grid in the month of September 2002, and ever since the plant has operated for 2800 hours exporting 1.2 million units to the grid. The average diesel replacement recorded is about 68%, with specific biomass consumption being 0.6-0.7 kg/kWh. Initially LDO was used as a fuel in diesel engine for dual-fuel operations; however, in the recent times furnace oil has been adapted in order to reduce the operational costs. Apart from generating electricity, the unit has recovered about 30 tons of coconut char with iodine no. of 550 to be sold as activated carbon. In the next phase of installation, the company proposes to install an identical capacity gasifier coupled to 100% producer gas engine. This plant has been manufactured and installed by Energreen Power Ltd, Chennai. Upon successful demonstration, the industry has received partial financial assistance from MNES, Govt. of India.

Desi Power Orchha Pvt. Ltd, Orchha

Development Alternatives an NGO has a hand made paper unit at Taragram, Orchha, Madhya Pradesh. To meet their electrical power requirements, a 100 kg/hr gasification system was installed to fuel 2 x 66 kVA diesel engines (Kirloskar Oil Engine make). This project was conceived to operate with a locally available feed stock called Ipomea (Besharam in local language), which is a weed and does not have any usage. The gasifier installed in April 1996 completed about 7100 hours of operation and subsequently it was replaced with a superior version gasifier (reactor lined with ceramic tiles) in February 1999.



Year-wise performance of Orccha plant



No. of units produced per Litre of diesel in dual-fuel mode

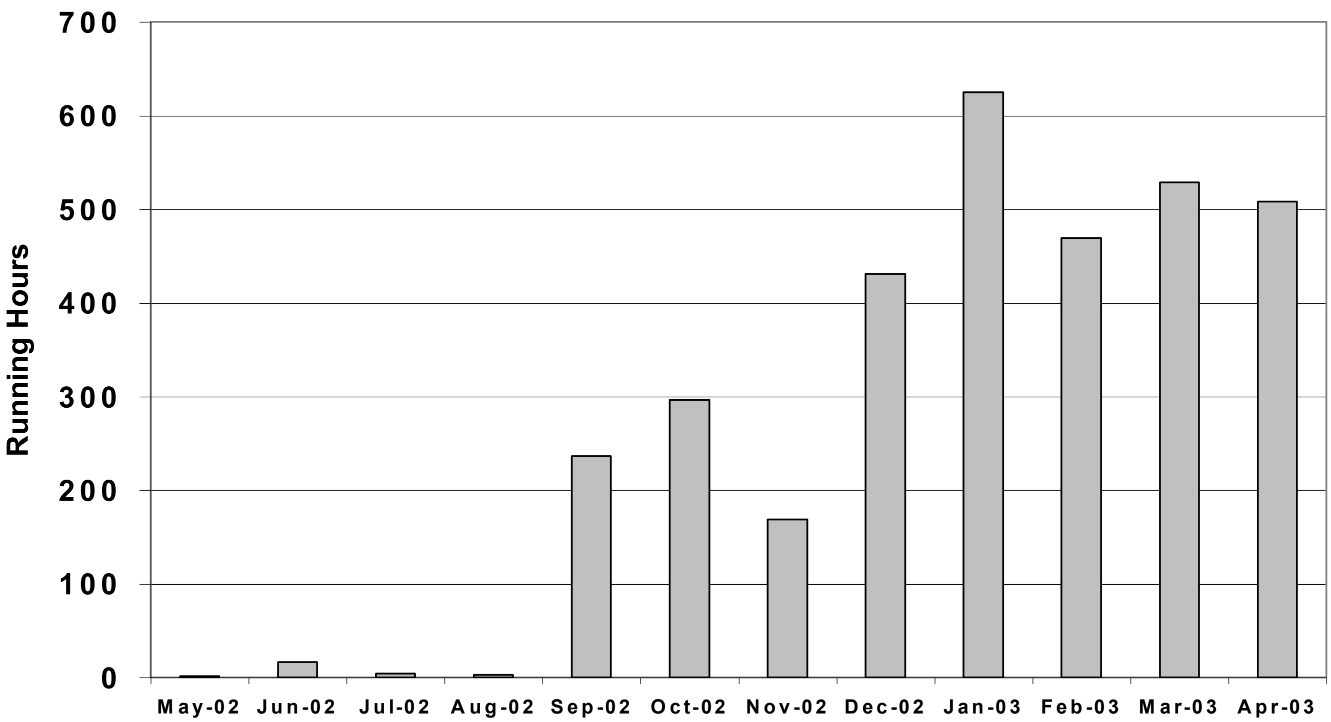
Performance and Status

The new system has so far operated for about 6200 hours (8-10hrs/day) with diesel replacement as high as 86%. The power plant has totally generated about 0.46 million units at an average diesel replacement of 65%. This plant has been manufactured and installed by M/s Netpro, Bangalore. Upon successful demonstration, the industry has received partial financial assistance from MNES, Govt. of India.

Sir M Visveswaraya Institute of Technology, Bangalore

2 x 100 kWe rating gasifier systems have been installed by M/s Netpro at Sir MVIT, Yelahanka, Bangalore in the year 2002. The gasifer is of 135 kg/hr each, coupled to 2 x 60 kVA and 1 x 140 kVA diesel generator set. The power package is meant for captive power generation with an average load of about 100 kWe. Among the two gasifiers, one is an older version, which consists of a reactor with a grate, gas cooling and cleaning system –with sand filters and other a newer version with screw based extraction system for the reactor and a superior gas cleaning system – with chilled water scrubber and fabric filter. The plant is currently under operation and maintenance contract with Desi Power Ltd, which in turn sells electricity to the institution. The power plant operating with locally sourced Eucalyptus wood has so far clocked about 3800 hours of operation generating about 0.23 million units of electricity. The average diesel

replacement attained is about 67%. This plant has been manufactured and installed by M/s Netpro, Bangalore. M/s Desi power are contracted for operation and maintenance of the plant. Though not conceived, the plant is generating charcoal (~2% of the feed) as the by-product. This charcoal has been analysed to have an Iodine no. of about 700, which is much superior compared to coconut char.



Vellore Institute of Technology, Vellore

Vellore Institute of Technology is a technical educational institute, wherein a 100 kWe gasification system has been installed on BOOT basis. The project has been financed by DesiPower and partly by Govt. of Netherlands. Since its commissioning in 2002, the plant has operated for about 500 hours generating about 30000 units, with average diesel replacement being 80%. In a continuous mode of operation, at constant load of 80 kWe, an average diesel replacement of about 93% has been recorded.

R&D/Other Installations

Central Building Research Institute, Roorkee

This is a project that was taken in collaboration with the CBRI to conduct research and exploring technical and economic feasibility of employing gasifiers for curing bricks and tiles. A gasifier was retrofitted to their existing kiln in the place of the conventional wood fired burners. The system comprises of reactor with grate, gas cleaning system and burner system. The system was operated using a mix of jungle wood and cotton stalks. Trials have been conducted and the results shown in the following table.

Date	Biomass	Drying time, hrs	Biomass used, kgs	Soaking temperature above ambient, ^{0}C
May 98	Wood+ cotton stalk (50 – 50 mixture)	20	1950	807
April 99	Wood	26	3070	925
June 99	Wood	25	3390	940
Nov 99	Wood	20	2700	850
March 2000	75% wood + 25% cotton stalks	22	2065	920
April 2000	50% wood + 50% cotton stalk	20	2220	910

The above trials indicated that a saving of 30 -35% biomass was possible by using gasifier as compared to conventional drying method. It was inferred from these trails that for applications which require higher temperatures (>940 C), employing a recuperator for preheating the combustion air would be useful in attaining higher furnace temperatures.

Chatel-St-Denis, Switzerland

This Indo-Swiss collaborative programme sponsored by the Swiss government was conducted by the CCC in Chatel-St-Denis, Switzerland. The gasifier plant was manufactured and exported by M/s Netpro, Bangalore in November 1995. The project was implemented in two phases. In the first phase, the performance of the gasifier as well as its gas treatment system was established. In the second phase, a complete cogeneration plant consisting of the following elements was operated: (a) The gasifier, (b) gas treatment system, (c) gas engine and (d) water treatment system.

The gasification plant is a fully automated plant comprising sub-systems like the fuel feeding, ash handling and control system for automation. In the first phase of the project, the plant was tested using a variety of biomass and with different moisture content and performance assessed. The parameters measured were with respect the gasification efficiency, gas quality and effluent levels. Long duration tests, including a 150-hour non-stop were conducted in order to examine issues such as reliability in operation, maintenance etc. In the second phase of activity, a Liebherr gas engine (original rated at 100 kWe on natural gas) was integrated and tested with the gasifier. The gas engine delivered a maximum output of 55 kWe. Trails for 500 hours duration indicated showed the engine's combustion chamber to be clean without deposits. Another outcome of these trails was that the engine emissions in terms NOx was much below the qualifying Swiss environmental norms. However, the CO emission was found to be higher, which was subsequently reduced by adapting a oxidation catalytic converter. The test results on the gasifier- engine system during first and second phases were encouraging and could meet the Swiss environmental norms.

Status

An outcome of this gasification project was the formation of a company called XYLOWATT, which is catering to European markets in terms of supply of energy efficient gasification system. In fact, XYLOWATT has installed their first showcase plant of 75 kg/hr capacity at Bule in Switzerland.

Educational Institution Installations

In terms of education, it was thought important that unless technical institutions have an exposure to the new technology and the students get to know the possibilities, it is difficult for a wholesome growth of the new energy services. With the support of Government of Karnataka, two systems have been set up in engineering institutions — National Institute of Engineering, Mysore and Gogte College of Technology, Belgaum. In these institutions, the system will have multiple roles – (a) the system is intended to generate electricity at a rate cheaper than the tariff they need to pay to the electrical utility, perhaps by 20 to 25%, (b) student projects can be taken up on aspects related to the technology, (c) user awareness enhancement takes place when visiting the institution or when open-house is held, and (d) selective consultancies can be taken up as found necessary. The 75kg/hr system has been run for about 200 hours at Mysore and has been demonstrated to benefit the college in terms of reduction in electricity tariff. Other similar projects would be needed across the country.

75 kg/hr gasifier system at NIE, Mysore

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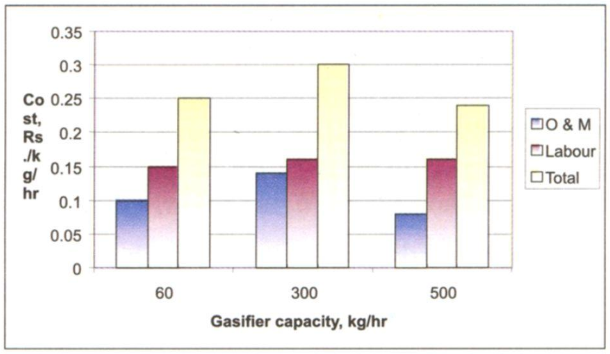
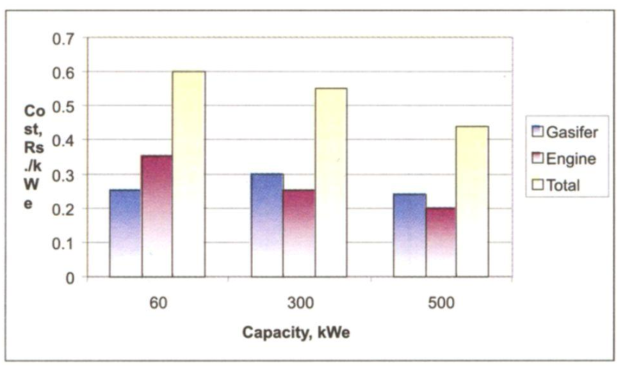
Economics of operation

Typical Capital cost* Rs. 3 to 4 Million at 100 kWe capacity
Rs.35 to 40 Million at 1MWe capacity



Distribution of cost towards O & M and labour for operating a gasifier system



Distribution of cost towards O & M and labour for a gasifier and engine system

Fuel cost Rs. 1 to 1.5 per kg
Fuel consumption 1 to 1.2 kg per kWh

* Depending upon the configuration

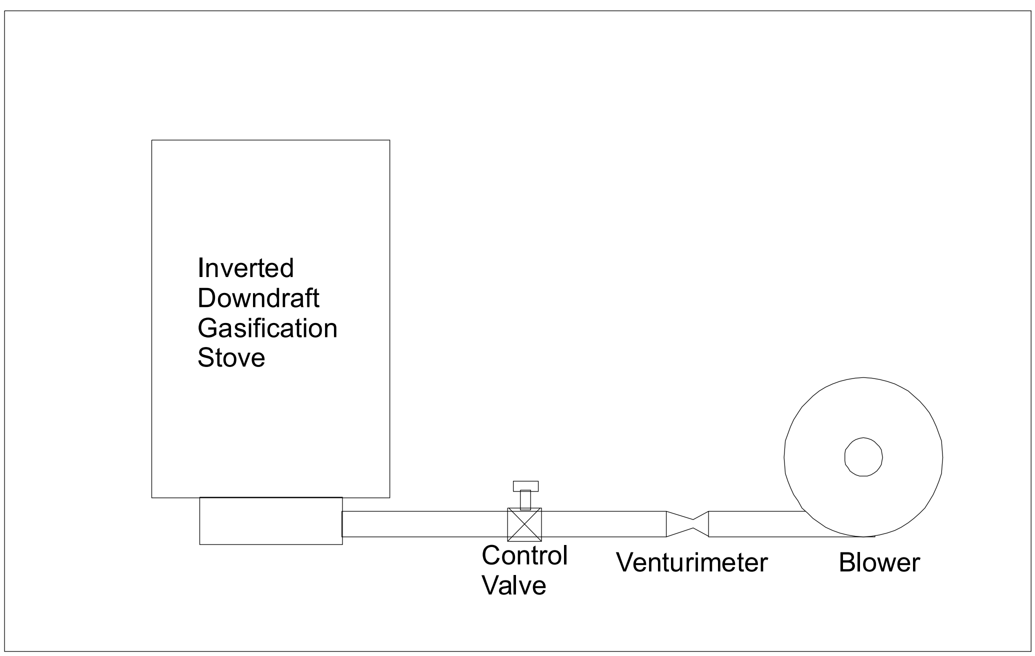
Appendix – I

Study for estimating bed velocities for different briquetted fuels

A study was devised to understand the behaviour of ash fusion with different briquetted fuel. The purpose of this is to observe the effect of air mass flux on the ash fusion behaviour of different fuels.

For the above purpose an inverted down draft gasifier stove was used with controlled superficial velocities. The mean velocity of air without accounting the packed column is called as superficial velocity. The experimental set up is shown in the figure below.

In the inverted down draft gasifier the fuel charge is stacked in the reactor and lit on the top. This layer forms the hot charcoal bed. The flaming pyrolysis zone is below this layer. The unburned fuel is at the bottom of the pile and primary air for gasification enters at the bottom and moves up, forming gas in the flaming pyrolysis zone.



Schematic if Reverse down draft gasification stove experiment

However the inverted down draft gasifier will work in batch mode unlike the ordinary down draft gasifier. The results of the experiments are shown in table below.

Results of the experiments

Briquettes used	Air Velocity, m/s	**Observation**
Marigold	Upto 0.16	No Clinker found
Ground nut shells	Upto 0.26	No Clinker found
Chilly waste	Upto 0.17	No Clinker found
Rice husk	Upto 0.21	No Clinker found
Rice Bran	Upto 0.3	No Clinker found
Coirpith	Upto 0.1	No Clinker found
Coffee waste	Upto 0.17	No Clinker found

It is clear that critical superficial velocity is around 0.1 m/s.

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Patents

List of patents filed

Sl.No.	Country	Application No.	Title
1	India	1568/Mas/96	A process of removing hydrogen sulphide from a gas mixture
2	India	2773/Mas/98	Biomass Gasifiers
3	Switzerland	1840/99	Biomass Gasifiers
4	Srilanka	12235	Biomass Gasifiers
5	Brazil	P10107342-7	Biomass Gasifiers
6	India	742/Mas/2001	C_n technology for cleaning tar and dust laden gases for use in reciprocating engines / gas turbines for power generation
7	Japan	2002-41620	Biomass Gasifiers
8.	Thailand		Biomass Gasifiers
9.	India	143/Mas/2003	A novel process and apparatus for the manufacture of precipitated silica from rice husk ash

List of IISc Gasifier technology licensees

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