Small scale clean combustion of solids – biomass

- Background – liquid and solid bio-fuels
- Clean producer gas (PG) generation
- Combustion of PG in engines
- Closed coupled gasification – combustion in stoves and small combustion devices

In all the cases, laboratory experiments, modeling the process, computer simulations, large scale field deployment, feedback, redesign have got done.

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Background

- Amongst 1st and 2nd generation fuels, 2nd generation fuels are still some time away.
- 1st generation (liquid) bio-fuels have significant solid residues.
- In some cases, the solid residues have toxins.
- Roughly 70 + % of the output constitutes residues.
- Ways of using the waste residues for societal purposes must be found.
- Research on 2nd Generation fuels is underway at IISc with MNRE support (through gasification route)

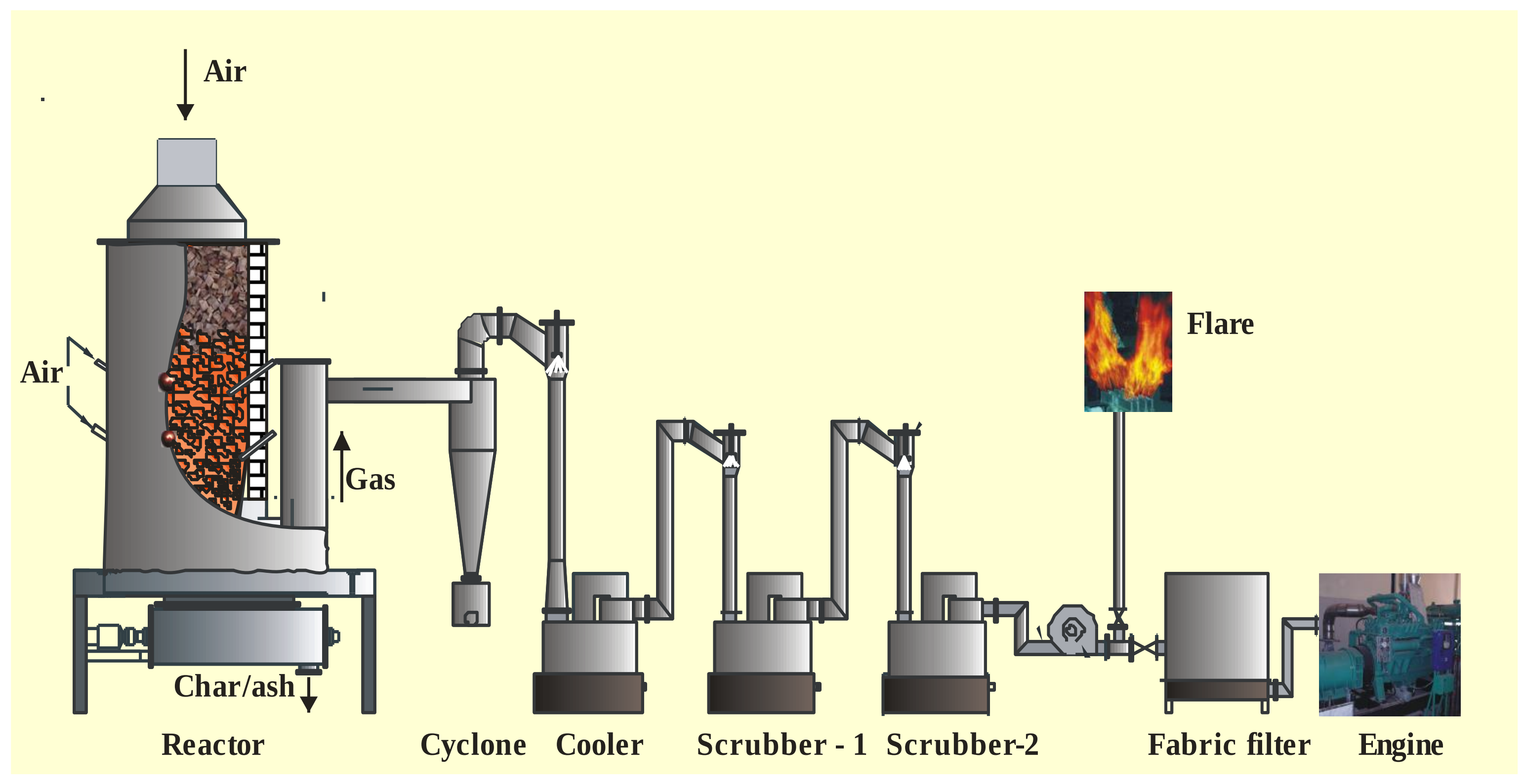
Hence, conversion of solid to gaseous fuels is the core step…….

Clean producer gas (PG) generation

- Fuel-flex, open top, staged air injection (also termed re-burn) gasification technology developed over 25 years

Thirty tests each of 10 hour duration over several years with several collaborators, inspectors with a variety of biomass – wood pieces, coconut shell, briquettes of sawdust, waste from biogas plants, apart from over several hundred in-house test runs with instrumentation on a variety of size of reactors (1 to 500 kg/h)

Open Top downdraft re-burn Gasifier (IISc) for electricity



Ceramic reactor to withstand high temp oxidizing and reducing environment; bottom screw system meant for ash extraction (high ash biomass)

Generation of activated carbon with surface area of ~ 450 m^2/g in the bottom section (500 °C)

Cooling and cleaning train to get dry gas at (P + T) < 2 ppm

Gas composition: 20 % CO , 19 % H_2, ~ 1 % CH_4, 10 % CO_2 and rest N_2
(Note that CO burns slowly, H_2 burns very fast)

1KgPH DINJAM PLANT

System cost~
150000 Rs/kWe

Investment ~ 60 million Rs/MWe

Fuel cost : 2 to 2.5 Rs/kWh,
O & M ~ 1.0 Re/kWh
Financial cost ~ 0.5 Re/kWh

Cost of energy ~ 3.50 to 4.00 Rs/kWh

BMC GASIFIER PLANT(1700Kgph)

Practical issues examined

What controls fuel-flex feature?

Air flow distribution inside controls the ash fusion vs. tar generation higher temperatures favors the former and lower temperatures favor the latter.

Use solid blocks – cut/chipped wood or briquetted biomass

Role of size: Minimum, ~ 3 mm thick flakes, say, below which tar is significant. Tar generated is not broken down.

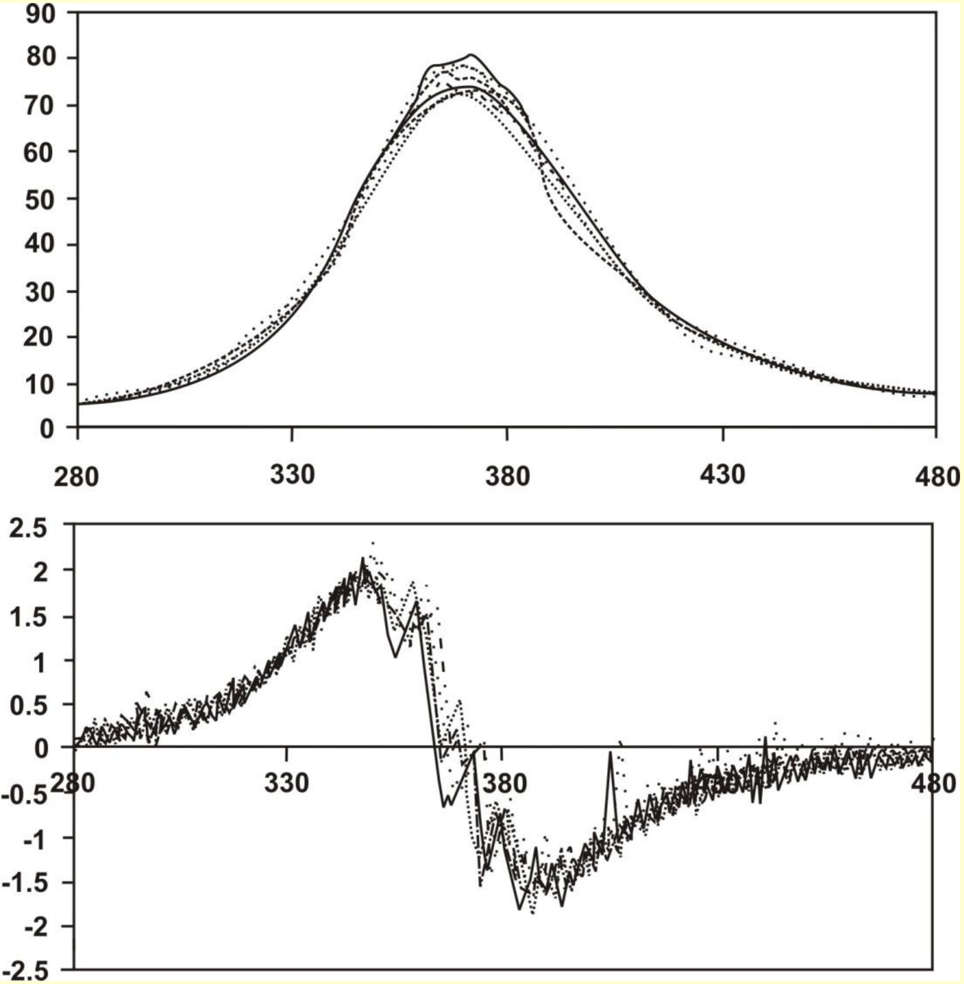
Role of moisture: Because there is expectation (some times too strongly in Europe) that things must be handled on an as-is where-is basis. This leads to double taxation! One on evaporating the moisture and another due to reduced peak temperature

Role of ash composition: Presence of Potassium reduces the ash fusion temperature. Hence increase in bed temperature leads to ash fusion

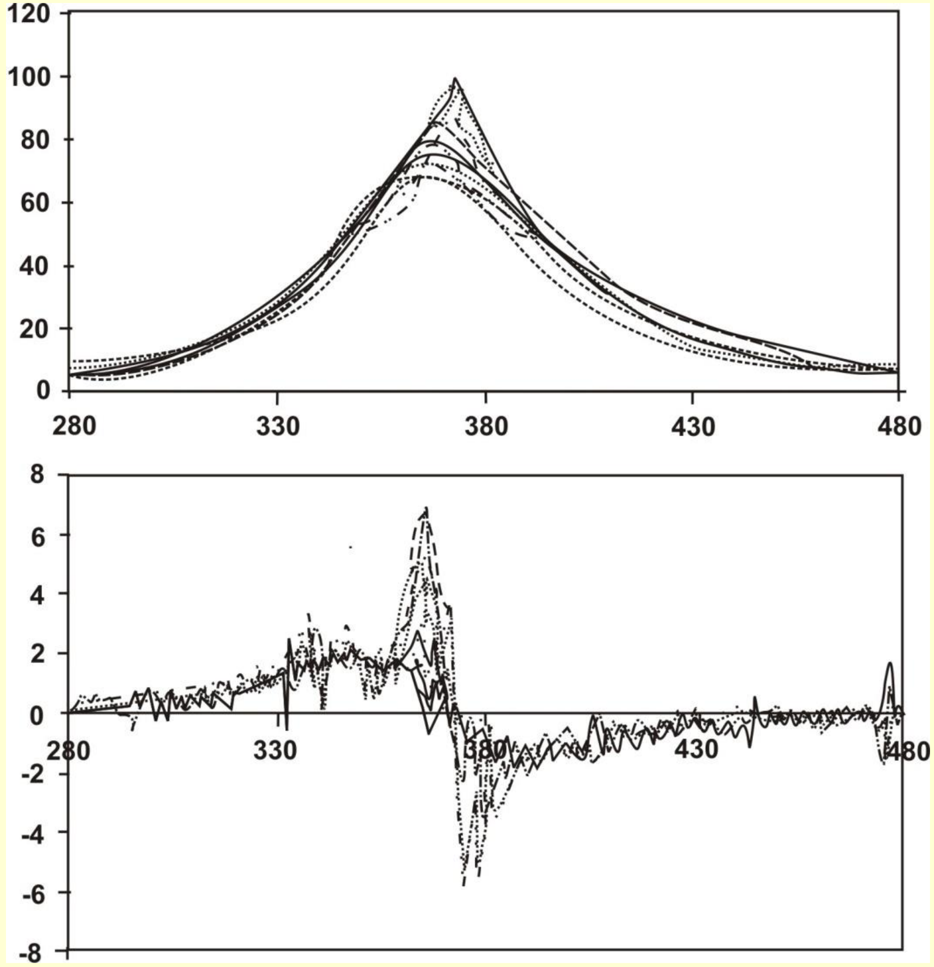
Thus to design the system one needs to arrange for a minimum bed temperature to crack tar and not too-high a temperature to avoid ash fusion.

Combustion of PG in engines

1. Dual-fuel operation in diesel engines (Compression ignition) is one standard route. One can replace ~92 % diesel/fuel oil. Large engines pose challenges since the pressure rise rate goes beyond acceptable limits at high diesel replacements.
2. Producer gas operation in spark-ignited engines needs a special carburetor since $A/F]_{PG}$ ~ 1.4 compared $A/F]_{NG}$ ~ 20.
3. Since (PG + air) has a 20 % lower cal value compared to (NG + air), peak temperatures are lower (by 10 %), number of molecules decrease on moving from reactants to products, Peak power from PG is lower than from NG
4. But PG has a higher octane number compared to NG. This permits operation on PG at higher compression ratios and hence one can derive higher power off-setting the loss from other aspects.
5. These have been experimentally examined and studied computationally using 0-d model and some 3 –d CFD to understand the flow features.



Diesel mode



Dual-fuel mode (80 % diesel replacement)

p (above) and dp/d (crank angle) (below) vs crank angle

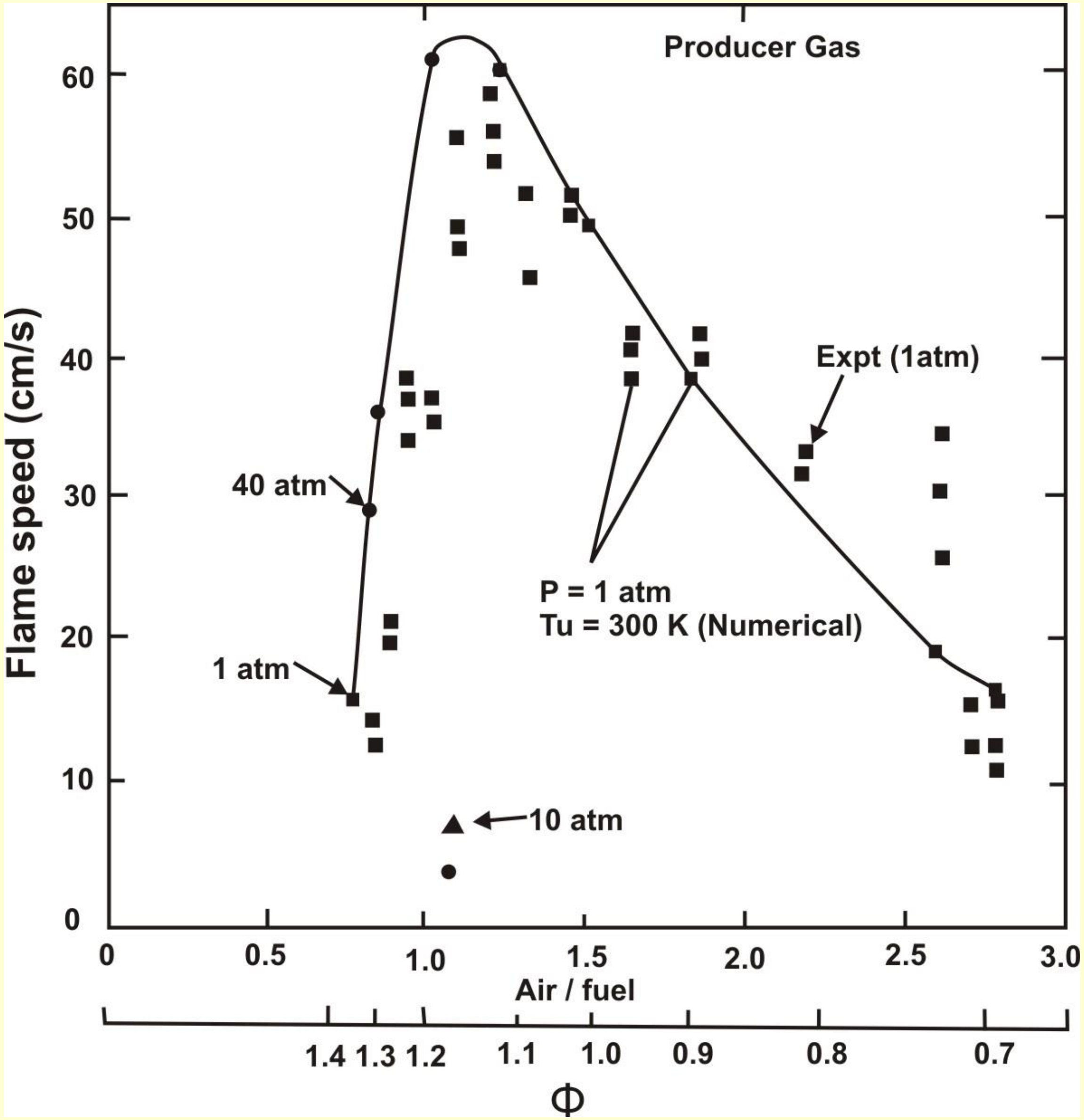
Analysis of Producer Gas

Reasons for de-rating with PG

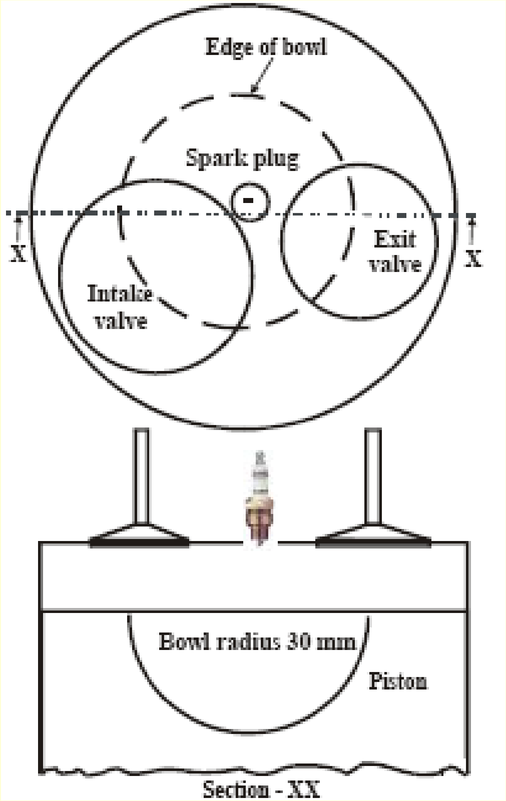
- **Energy density PG < NG by 20 - 23%**
- **Sub-optimal – Turbocharger**
- **Reactant:Product < 12%**

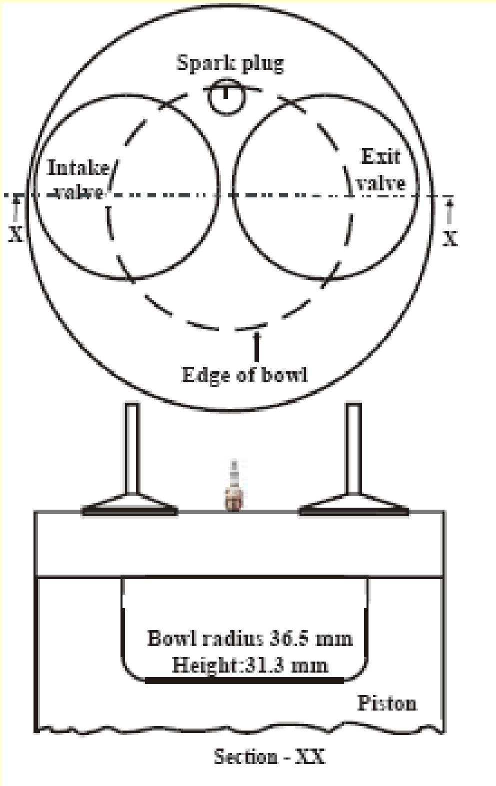
Properties of Gaseous Fuels

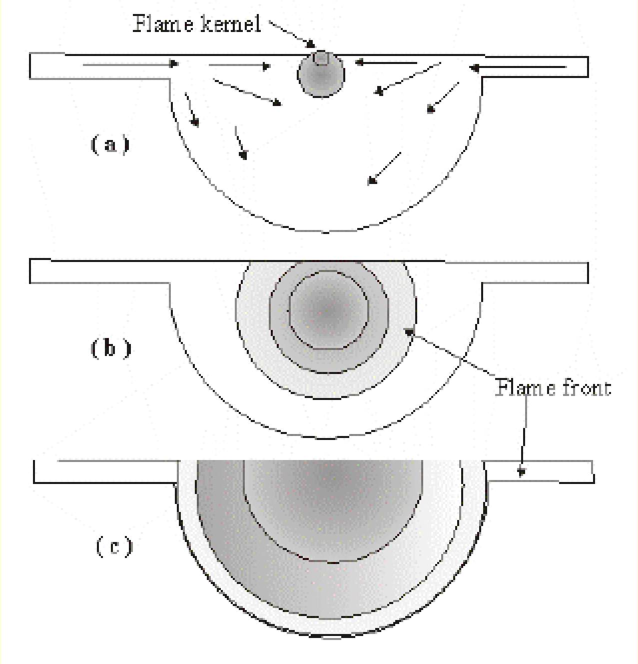
Fuel + Air	Fuel LCV, MJ/kg	Air/Fuel @ (Φ =1)	Mixture, MJ/kg	Φ, Limit		S_L (Limit), cm/s		S_L Φ =1, cm/s	Peak Flame Temp, K	Product/ Reactant Mole Ratio
				Lean	Rich	Lean	Rich			
H_2	121	34.4	3.41	0.01	7.17	65	75	270	2400	0.67
CO	10.2	2.46	2.92	0.34	6.80	12	23	45	2400	0.67
CH_4	50.2	17.2	2.76	0.54	1.69	2.5	14	35	2210	1.00
C_3H_8	46.5	15.6	2.80	0.52	2.26	-	-	44	2250	1.17
C_4H_{10}	45.5	15.4	2.77	0.59	2.63	-	-	44	2250	1.20
PG	5.00	1.35	2.12	0.47 a	1.60 b	10.3	12	50 c	1800 d	0.87



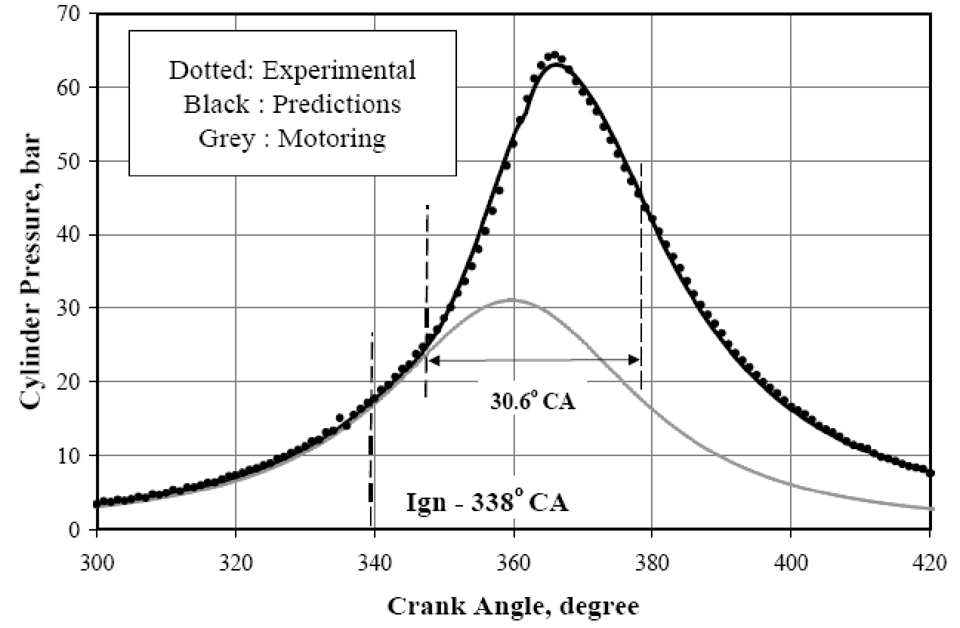
Flame speeds from experiments and predictions from 1-d unsteady flame code (IISc – 1987+)

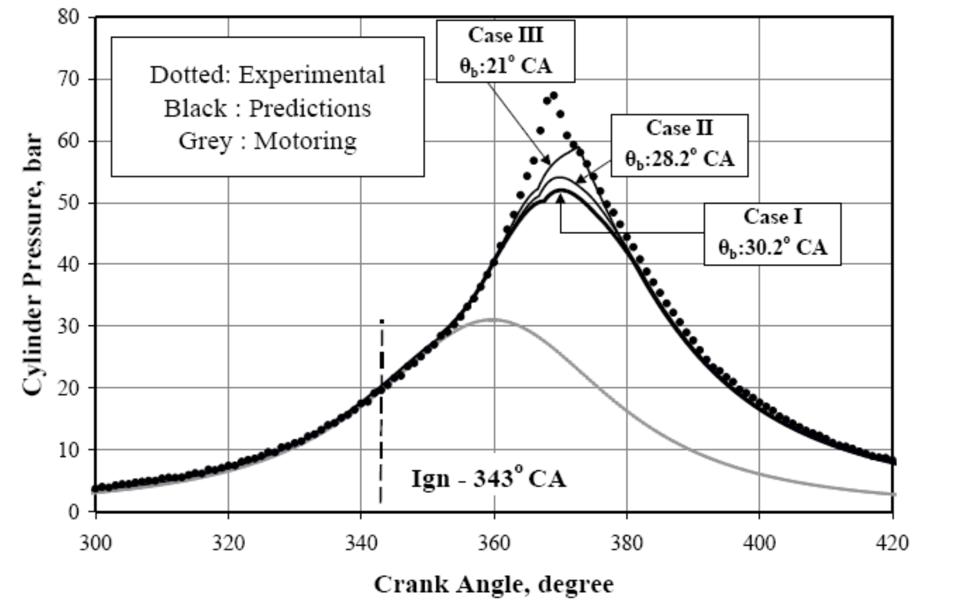






Small engine (3.7 kWe) Medium power engine (25 kWe) Model for computation





Ignition Advance = 22 degrees

Ign Advance = 17 degrees

CR = 17

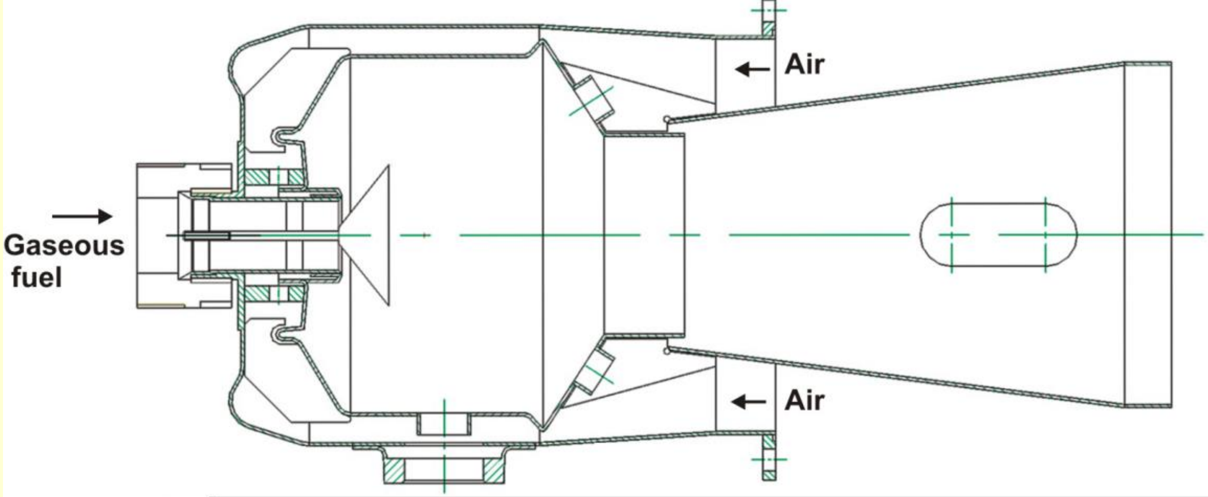
Predictions at CR up to 17 for ign advance > 20 degrees and for CR below 14 at all appropriate ignition advances (that give max power) very satisfactory.

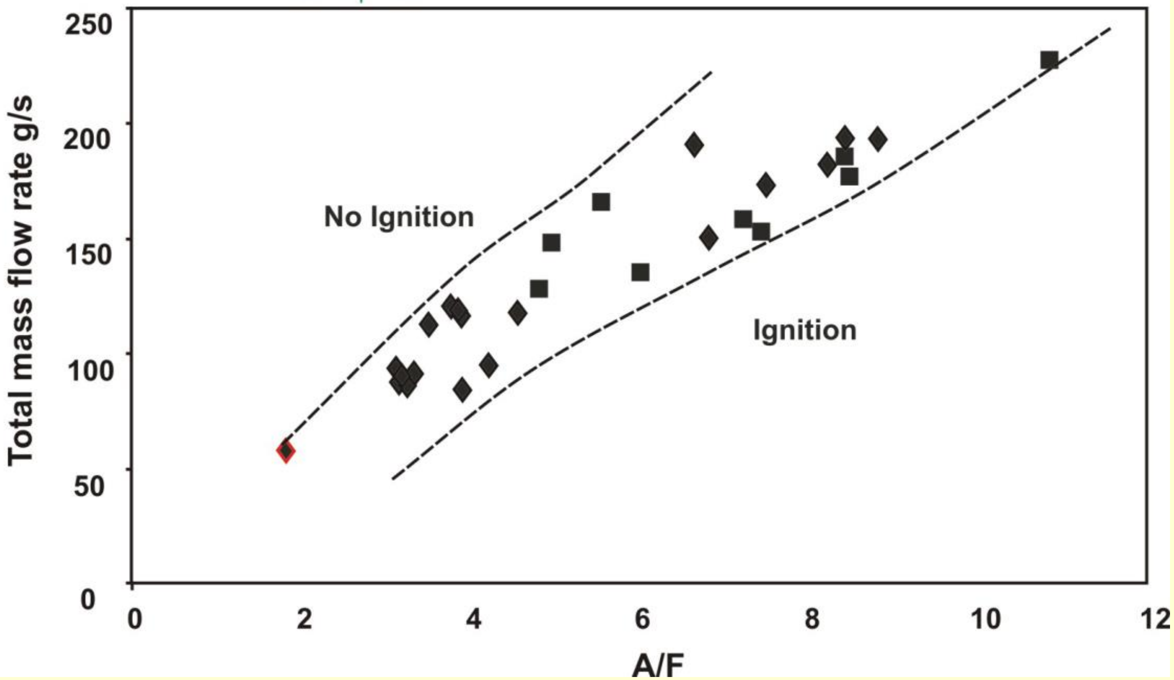
The flow behavior at low ignition advance has complexities that need more careful modeling.

Experimentally and computationally combustion is smooth over a range of Advances – Cetane number high

Table –7.5: Principal Results of 'Simple' Cases. MBF. Mass Burned Fraction (MBF) corresponds to 372° CA

CR	Ign, ° CA	Experiment		Prediction			
		Peak Pressure, bar	Occurrence, ° CA	Peak Pressure, bar	Occurrence, ° CA	Duration, ° CA	MBF, %
17.0	*26*	*60.9*	*366*	*60.8*	*365.8*	43.4	*100*
17.0	22	64.4	366	63.0	366.4	39.6	100
13.5	25	46.3	368	44.8	367.2	60.0	92
13.5	18	36.9	372	36.8	371.0	56.0	74
11.5	27	38.0	368	35.2	367.6	68.0	87



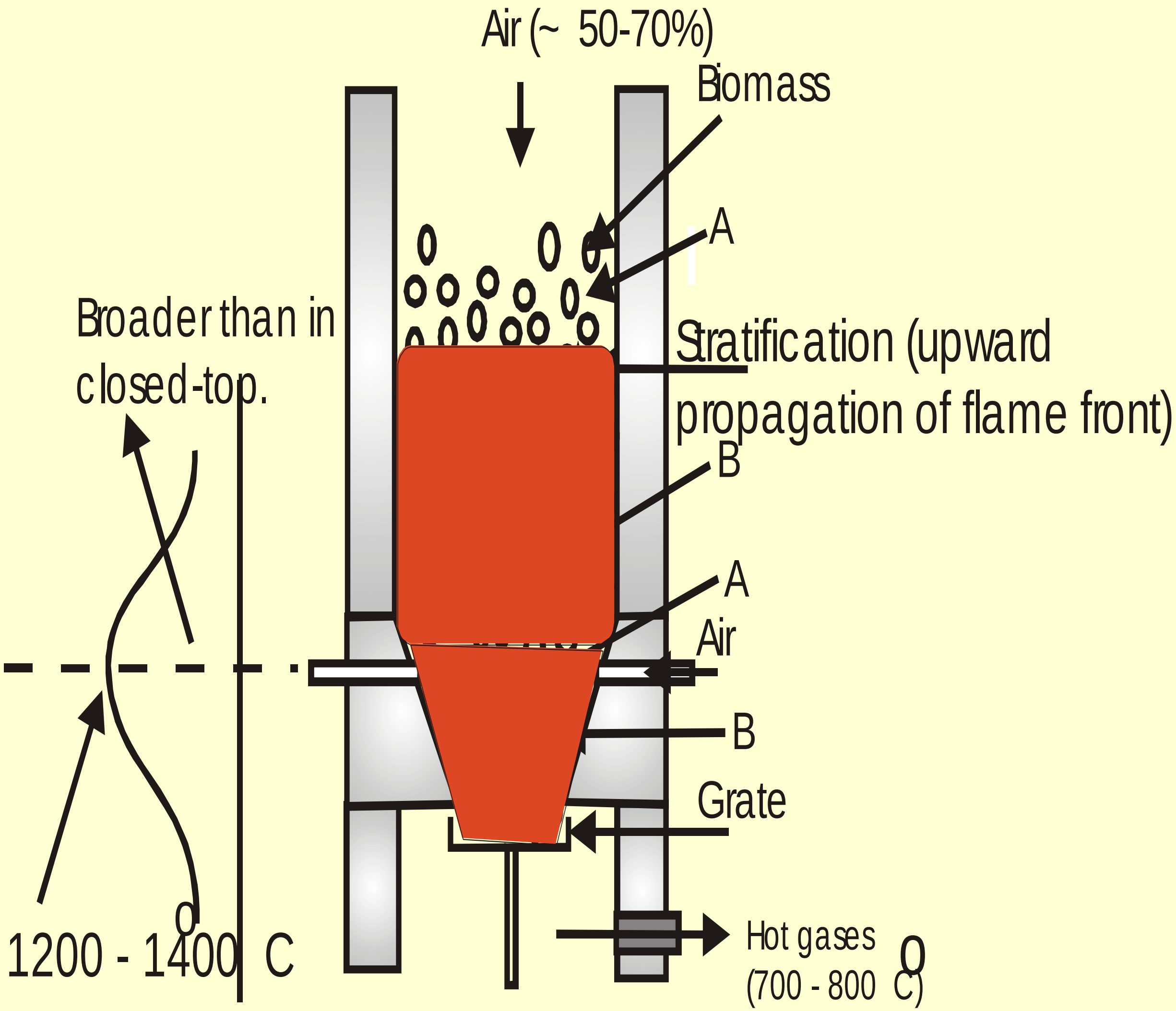


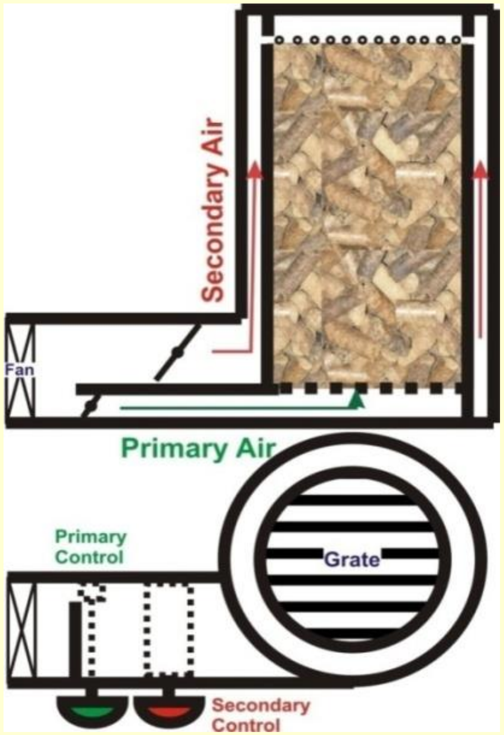
Results of ignition test on a gas turbine combustor modified to operating on PG

Closed coupled gasification – combustion in stoves and small combustion devices

- The idea of a gasifier stove – principle of operation
- A HELE Domestic stove for high density pellets
- Key questions on flaming and glowing modes and some answers
- Modifications on gasifier stove
- Horizontal gasifier stove for fire-wood. for pellets?

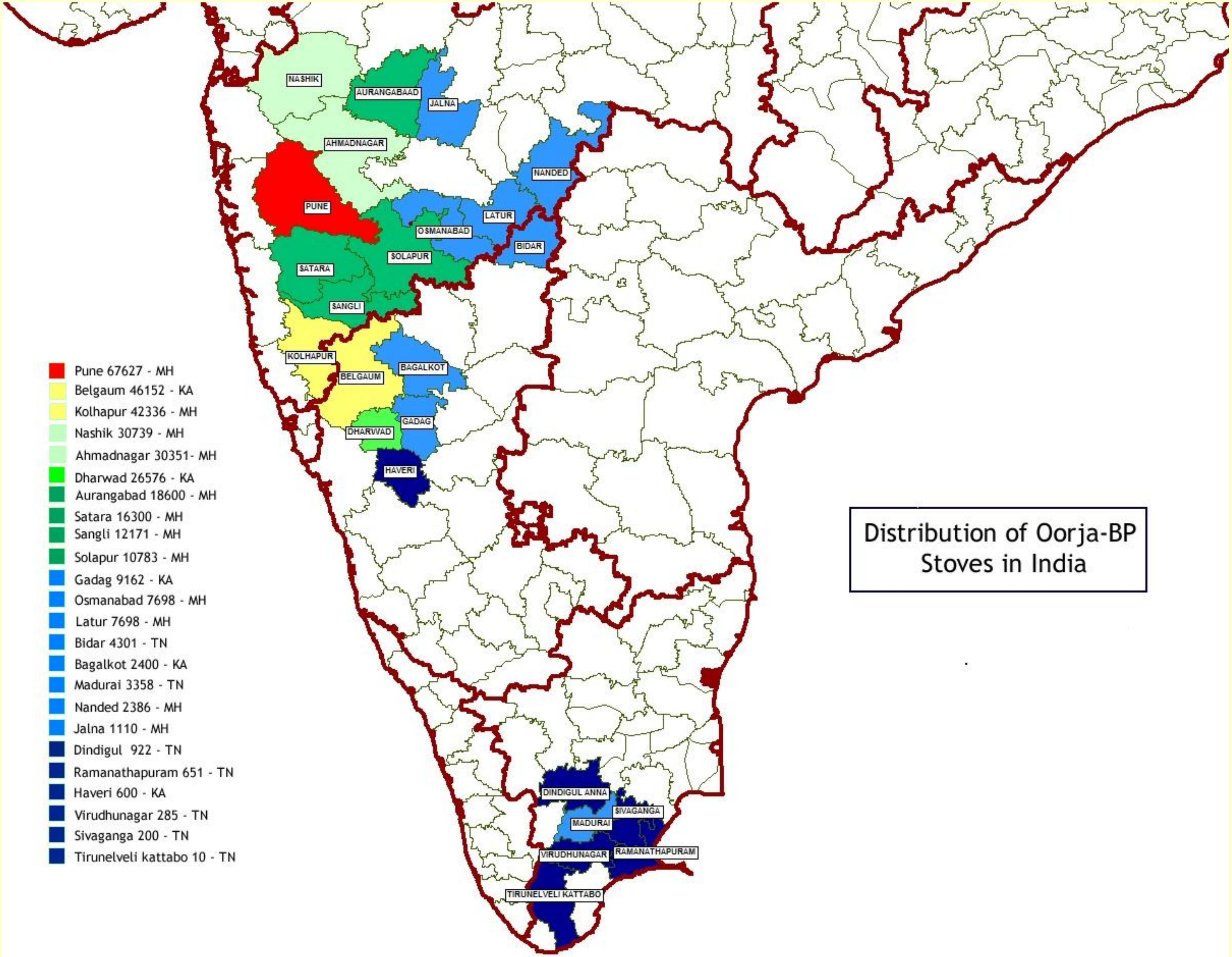
Domestic heat? – Reverse the downdraft gasifier



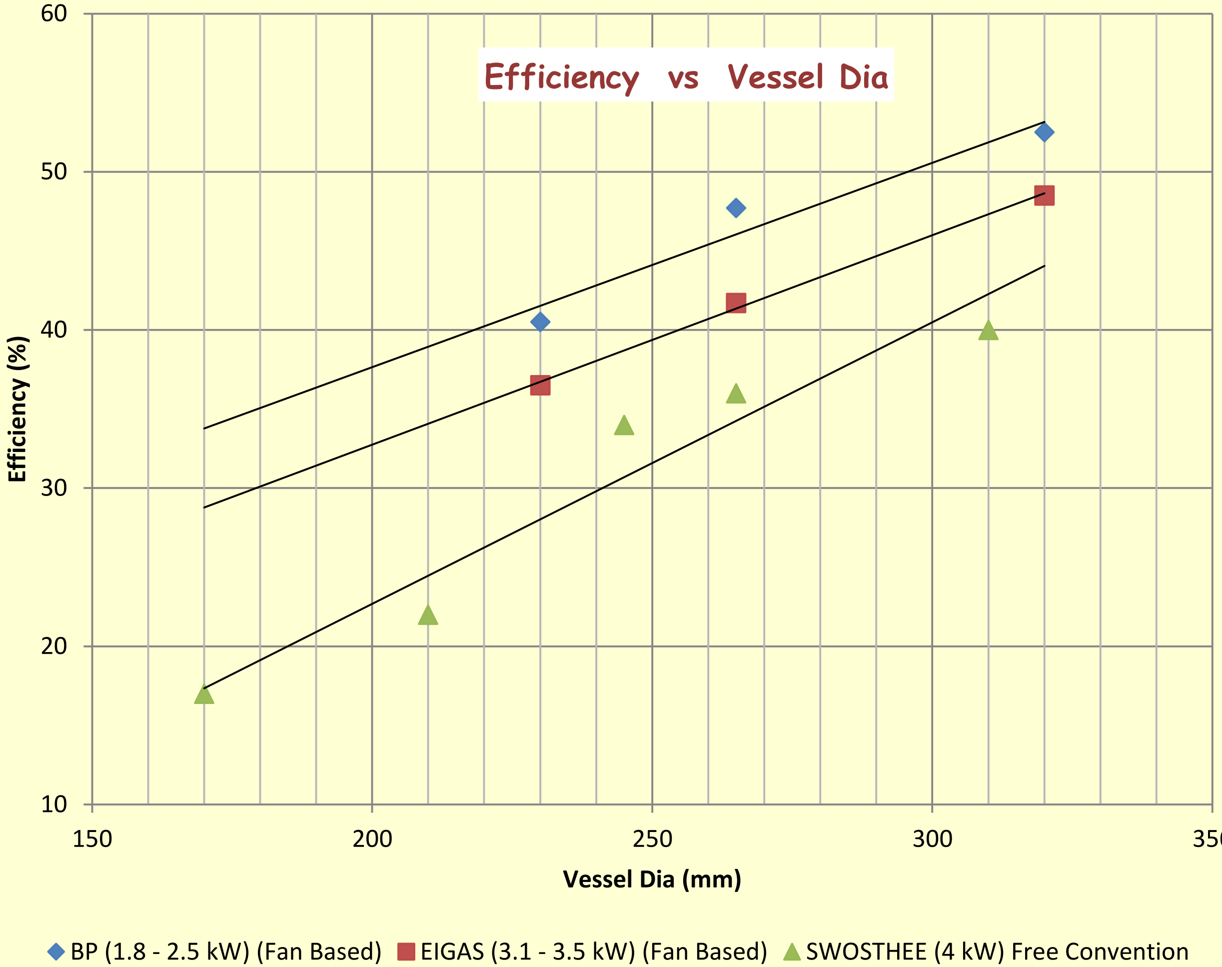


Close the side air nozzles; invert the gasifier

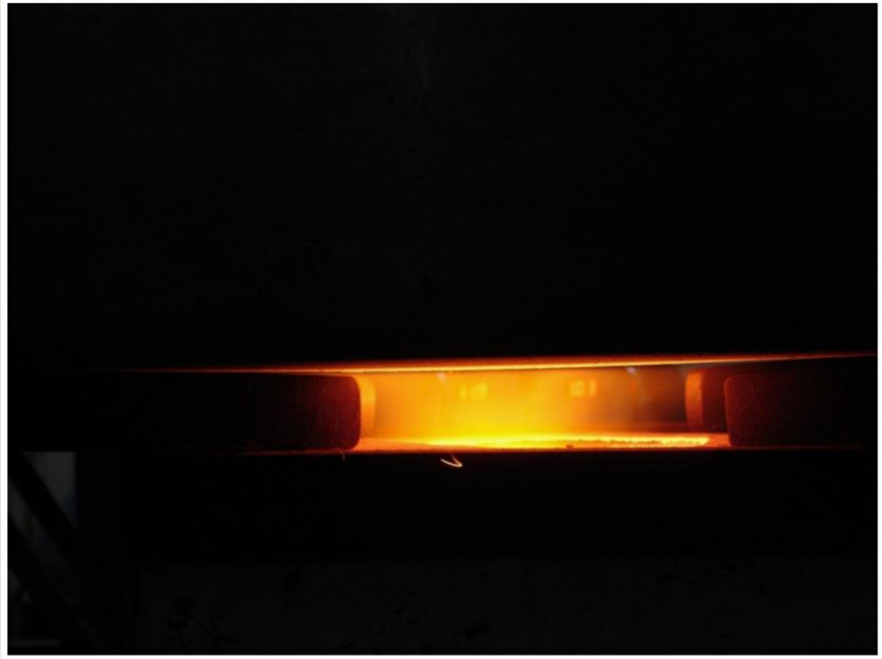
REDS – Gasifier Stove Tec transferred to BP, India and FEPL, Pune



FEPL, Pune has commercialized and marketed 500,000 stoves and sells 2000 tonnes of pellets every month.



Water boiling efficiencies in flat Al vessels with 230 , 265 , and 320 mm diameter carrying 2.5, 6 and 10 liters of water.



Design of a HELE fire wood continuous stove with new ideas –
Ejector induced air flow and horizontal gasifier (EIGAS stove).
The power drawn is 1.2 W for 4.5 kW thermal output. Eff. ~ 45 to 50 %

Ejector induced gasifier stove (10 kg/hr, 45 kWth) with a vessel at the top – uses 12 W power with an advanced high speed fan with levitating bearings. Notice the near transparent flame;
Used now for making Pattu in Kerala

Comparison of stoves for bringing to boil 5 liters of water

Stove	Fuel g	CO g	PM g	CO g/MJ	PM g/MJ
Three stone Fire	**1118**	56	2363	3.13	42.27
Ghana Wood	**996**	50	4287	3.14	68.32
20L Can Rocket	**733**	15	1289	1.28	15.12
Wood Flame Fan	**626**	**9**	48	**0.90**	**0.48**
Wood Gas Fan	**459**	**7**	**27**	**0.95**	**0.20**
Mali Charcoal	**674**	113	260	10.48	2.80
Gyapa Charcoal	**694**	135	587	12.16	6.52
Indian VITA Test 1	**1135**	38	1490	2.09	27.06
T-LUD	**933**	25	694	1.67	10.36
Institutional 310 Rocket	**483**	6	414	0.78	3.20
Lutfiyah's Improved Stove	**823**	16	1231	1.22	16.21
T-LUD	**1296**	18	437	0.87	9.06
BP Stove (IISc)	**380**	**4.5**	**6**	**0.75**	**0.06**
EIGAS - 1 (IISc)	**400**	**7.2**	**9.6**	**1.12**	**0.1**