Progress on Advanced Clean Biomass Combustion Systems for Domestic and Industrial Applications

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Background - 1

- Cooking at domestic, community, and hospitality industry is a primordial requirement of any society. In India and other developing countries, biomass based cooking has largely been the basis for a long time.
- Introduction of LPG and its progress introduction has influenced urban sectors nearly completely arising out of the availability of the gas stoves and more importantly, supply chain management.
- Rural house-holds and even moderately affluent communities living in inaccessible areas continue to depend on biomass based cooking.
- The introduction of improved cook stove program to reduce the indoor air pollution was in practice for over the last forty years.

Background - 2

- It has not been considered successful – the subsidy driven MNRE program has claims of large number of stoves disseminated, but of little effect on indoor air pollution.
- The entire program was free convection based stoves whose performance in field conditions is vastly different from that in a laboratory operated under controlled conditions.
- The realization that forced convection stoves could offer much better performance came in but somehow had to be fitted into the ineffective "subsidy" regime for which they were far too well accustomed – for understandable reasons.

Background - 3

- A disruptive approach of large scale introduction of LPG based stoves was put in place by the present Government. Approximately 50 million users have had a free supply of stoves and one LPG cylinder.
- A recent analysis showed that a substantial number of users had not returned for a refill. The reasons have been analyzed as due to
  a. Economic reasons of the cost of refill with the request for refill occurring once in more than several months,
  b. The location of the house-holds in relationship to distribution centers is too large to have a commercially satisfactory refill arrangement
  c. Alternate cooking arrangement using three-stone fire being always a sure back-stop arrangement despite it being “smoky” or causing eye-burns or other health issues.
- Thus as in earlier times, the need for clean biomass combustion systems – implying minimal emissions of undesirable components is important even now

The fuel- related issues

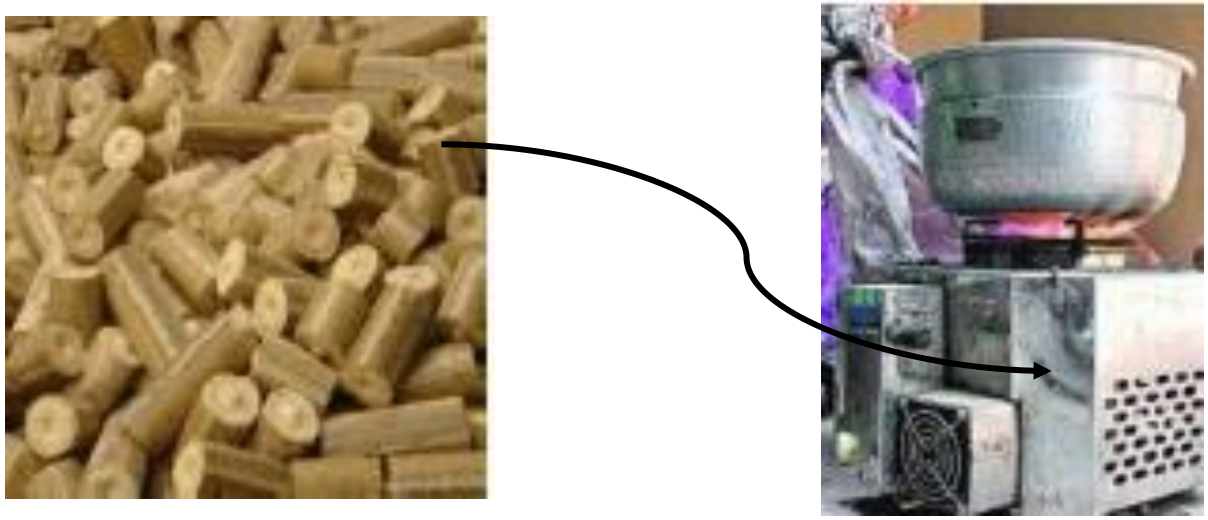
- In earlier times, split firewood – dry or otherwise was the only source of biomass fuel
- Over a time, deforestation was frowned upon and agricultural residues or prepared fuels from these were called upon to meet the rural fuel needs.
- Even when firewood was considered important because of on-ground assessment of its use, Governmental perceptions prohibited almost any effort to develop firewood based clean technologies.
- It was little realized that a wide range of agricultural residues available in different seasons were simply used in mud stoves or even improved stoves later without consideration of large emissions.
- It was also not realized that the size and shape (use of moisture in firewood was considered incorrect, but not dealt with professionally) had a strong influence on the burn rate (firewood with large cross section when split longitudinally would increase the burn rate depending on the net surface area over which the burn occurs).

Solutions needed and possible approaches

- One would need clean combustion devices for agricultural residues with low densities (50 to 300 kg/m^3 as against 500 kg/m^3 or more for firewood) and widely differing shapes and sizes
- One would need solutions for clean combustion of pellets produced from agricultural residues that have moderate ash content (say less than 10 %)
- One would also need clean combustion devices for firewood as it was clear that there are areas in our country and elsewhere, that firewood is the primary fuel.
- Forced convection device is an inevitable choice to ensure conversion of cooking fires into *Controlled Combustion Devices*
- Demands of combustion devices with limitations of height calls for horizontal combustion system as against vertically arranged systems.
- Clean combustion devices for domestic applications in the rural segment need to be affordable while being aesthetically appealing embedding high efficiency and minimal emissions in the design (since the latter two are less respected than the “looks” and “first cost”)
- Much has happened in these areas over the last decade and more particularly in the last five years……

What is it that has been done over the last 15 years? - 1

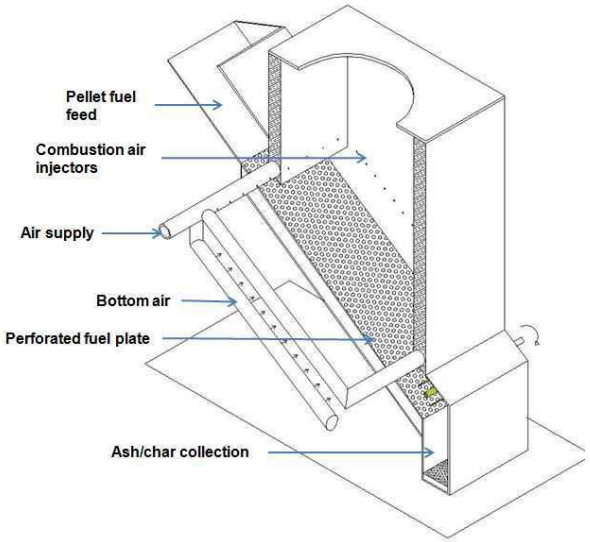
Based on tech transfer from IISc, BP-India produced and commercialized a single pan, forced draft, fixed bed pellet based cooking solution (at 0.75 kg/h) that was produced and test marketed to over 0.4 million house-holds between 2007 to 2010.



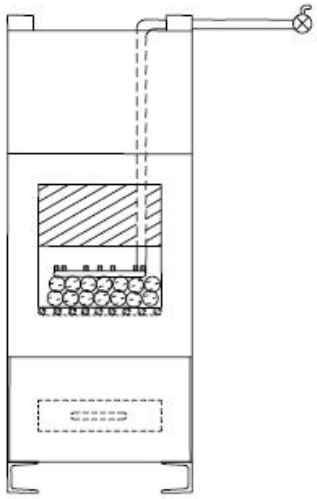
Its decline came about because the cost of fuel pellets based largely on bagasse and groundnut shells became unaffordable (Rs. 6/kg in 2007 to Rs. 12/kg in 2011 and Rs. 16/kg later) for the domestic environment. BP-India got transformed into FEPL, Pune that entered into higher power systems for hospitality industry. In 2017, it was transformed to FEPL-Thermax

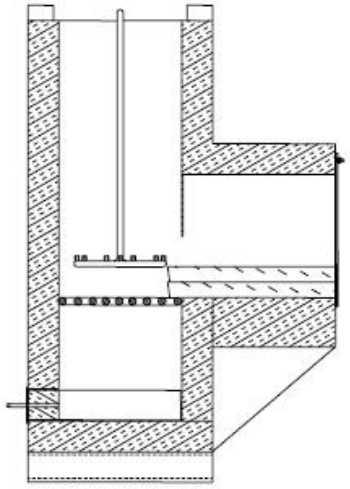
What is it that has been done over the last 15 years? - 2

- The design process for larger power systems (3 to 10 kg/h pellets) was provided through the work of Dr. Varunkumar (my teacher) when he was pursuing his Ph.D at IISc.
- During this period, FEPL wanted a continuous combustion device. This development at *Jain University resulted in tech transfer* of what is called **Enhanced Ejector induced hybrid gasifier stove** (E-HERS) that was a transform of **Ejector Induced Gasifier Stove** (EIGAS) built at IISc earlier. This helped pellets to move down aided by gravity along an incline.



The Enhanced Hybrid Ejector induced stove (E-HERS)



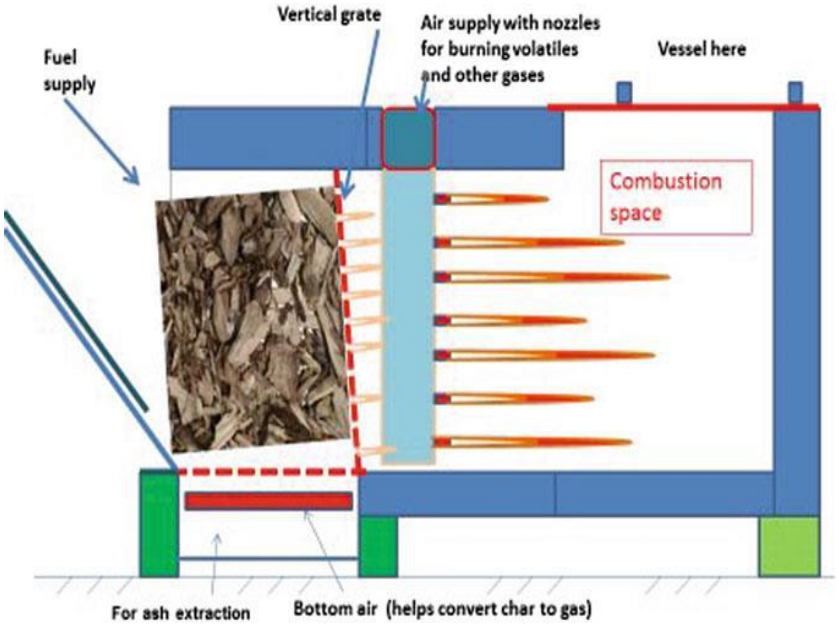


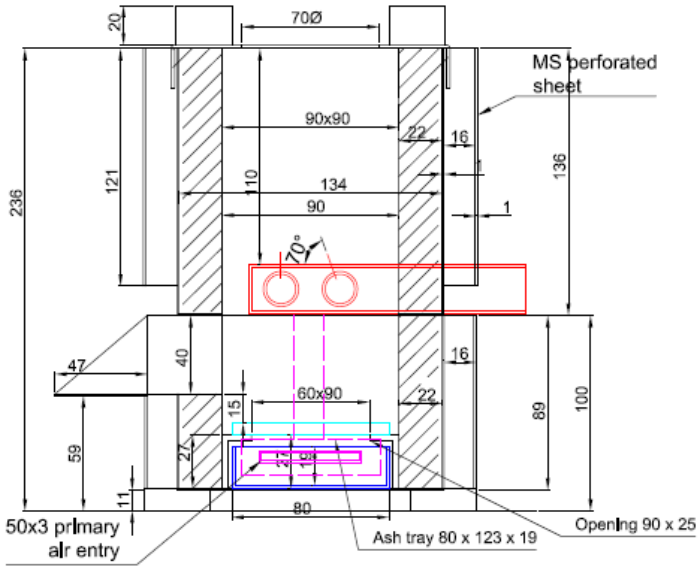
Ejector Induced GAsifier Stove

What is it that has been done over the last 15 years? - 3

- The issue of continuous operating system that can be used with wide range of agri based fuel with lesser degree of preparation became the subject of interest from this point onwards.
- The ideas of ejector based device needed a minimum of 10 m/s of jet velocity, which need limited electric power of about 2 W for 1 kg/h for the domestic system that has always turned out to be the most complex to design and produce at affordable prices (and so, more complex than “rocket science” the cliché used in most statement of complex designs)
- Around this time, the need for horizontal combustion device at relatively large throughputs (30 kg/h class) was set out for sand drying industry, the fuel being firewood.
- This led to the development of Horizontal continuous clean combustion device (HC^3D) with a wider spectrum of fuels (clean here refers to non-sooty, quasi-gasification combustion process with lifted jets).
- The abandoned firewood based combustion device got rejuvenated with ideas acquired till this time into vertical ejector biomass combustion device (VEBCOD) for continuous combustion of firewood like biomass.
- Much effort at FCRC has gone into testing these systems for efficiency and emissions and suggesting possible improvements.
- Technology practice of these is in place with Harit Avani Industries (Bangalore) and Synergy engineering and environmental solution, Imphal, Manipur

Clean combustion principles of HC^{3}D and VEBCOD





- The Horizontal Continuous Clean Combustion Device shown consists of the fuel feed zone and air supply ducts. There are two air supplies – one below the grate and one in the gas path.
- The bottom air allows gasification of char and the top air helps combustion of these gases and some volatiles – this is the reason for calling it as quasi-gasification.
- The cross section of the combustion chamber is filled with specific number of air ducts depending on power level. Each of the ducts has specific number of air nozzles. Jet diameters - 3 mm for small systems to 10 mm for large systems
- VEBCOD has similar features excepting that firewood is fed horizontally and burnt gases exit from the top. Free convection becomes a important aid.

Operation of HC^3D

- Stoves of different power levels (1 – 150 kg/h) have been built and operationalized in field locations for tens to thousand hours.

The early single pan stove being
Tested for efficiency and emissions at CDM, JU;
AGNI-SAKHI was the name it got at its birth!

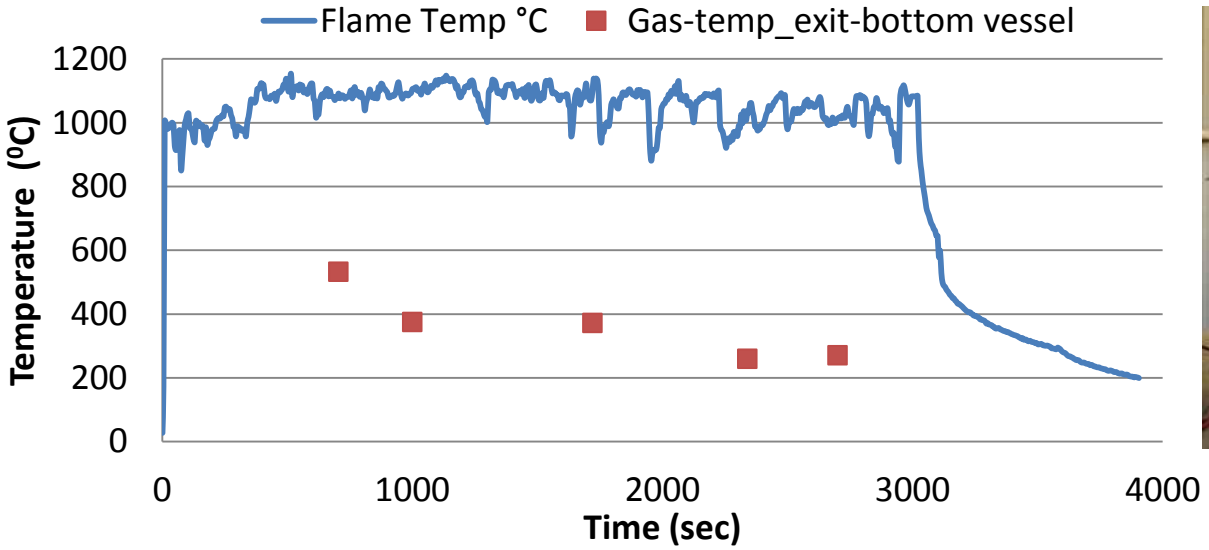
Two pan stove

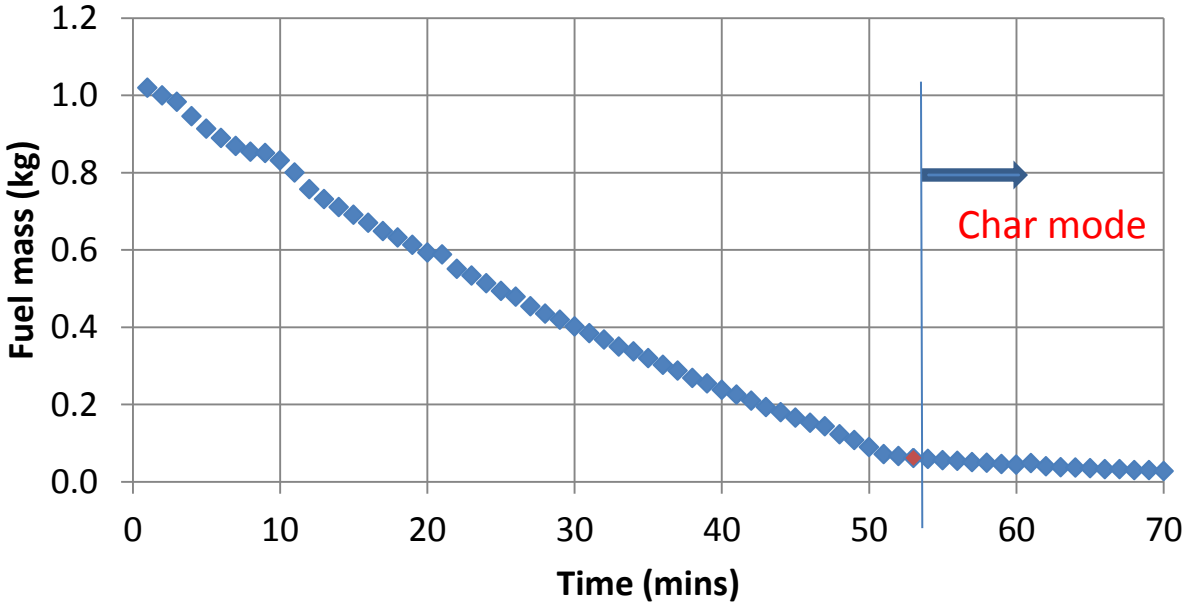
- Around this time, a suggestion was made that a two pan stove has value because generally two food dishes are cooked in every family.
- This would perhaps reduce the perceived cost of the stove as two meals can be cooked simultaneously.
- As the combustion process is horizontal, two vessels can be accommodated with the first vessel being set so that there are no air flow paths from the annular region of the first pan.
- The second pan arrangement can be set out with any vessel – shape and size.
- The ash extraction system is placed just below the fuel storage and gasification region. This separates the presence of char in the combustion zone making it close to a gasifier in operation

Biomass tested with the system

Final design of Agnisakhi with perforated outer covering deployed in 200 numbers to the field

Performance





Uniform combustion rate and combustor operation ensures high flame temperature and low CO emissions

Efficiency, Emissions – a comparison

Subject	Envirofit (Shell)	Oorja (Top-lit)	HC^{3}D (Present)
Consumption, kg/h	0.6 to 2, Operator dependent, usually at larger levels	0.6	1 kg/h single pan 1.5 kg/h 2 pan (a unique new design)
Power level , kWth	3 to 10	~3	4 kWth (single pan) 6 kWth (2 pan)
Fuel	Firewood, suggestions on the usage of dry fuel	Supply of prepared dry agro-residue pellets	Sized dry fuel - wide variety, density does not matter
Natural convection or fan based	Natural convection	Rechargeable battery based power supply to a specifically designed fan	Rechargeable battery based power supply to a specifically designed fan
In-situ combustion?	Yes	Gasification + combustion	Gasification + combustion
Continuous?	Yes	No, 60 to 70 mins duration	Continuous
Efficiency, 10 lit water	20 to 35 % Oper. dependt	45 – 48 %	36 – 40 %
Emissions	Largely sooty since users tend to derive high power levels	Independent of the user. Operator only controls the power of the stove	Simple operational procedure limits the emissions.
CO emission, g/MJ	2 to 3	1	0.08 to 0.1
$\Sigma CO/\Sigma CO_2$	0.02 to 0.04	0.015 to 0.02	0.008 to 0.01
Soot	Generally heavy	None	None
Particulate matter	3 to 10 mg/MJ, due to operator intervention	0.75 mg/MJ (due to low velocities in the critical zones)	0.8 to 1 mg/MJ

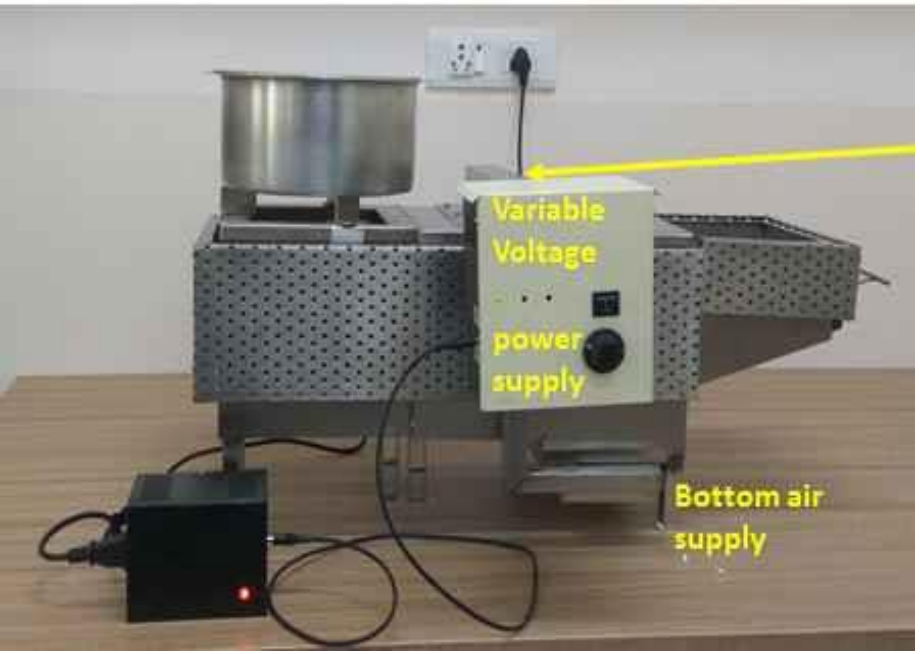
Really speaking, should we be bothered by water boiling efficiency?

- If we treat stove as a solid fuel combustion device and establish the combustion quality to be high – reduce emissions of CO – directly dependent of flame temperature with appropriate oxygen availability and reduce particulates by reducing the flow velocities of the stream made less inhomogeneous (enhanced mixing), do we really need to be concerned with water boiling efficiency issues?
- This is because a combustion device can be coupled to a variety of uses and even in one use like cooking people use a variety of vessels – bottom flat and round shaped, etc.
- Concern for utilization efficiency is unimportant for certification – depends on the application even for domestic cooking, let alone for community kitchens/hotels.

Learnings and Takeaways

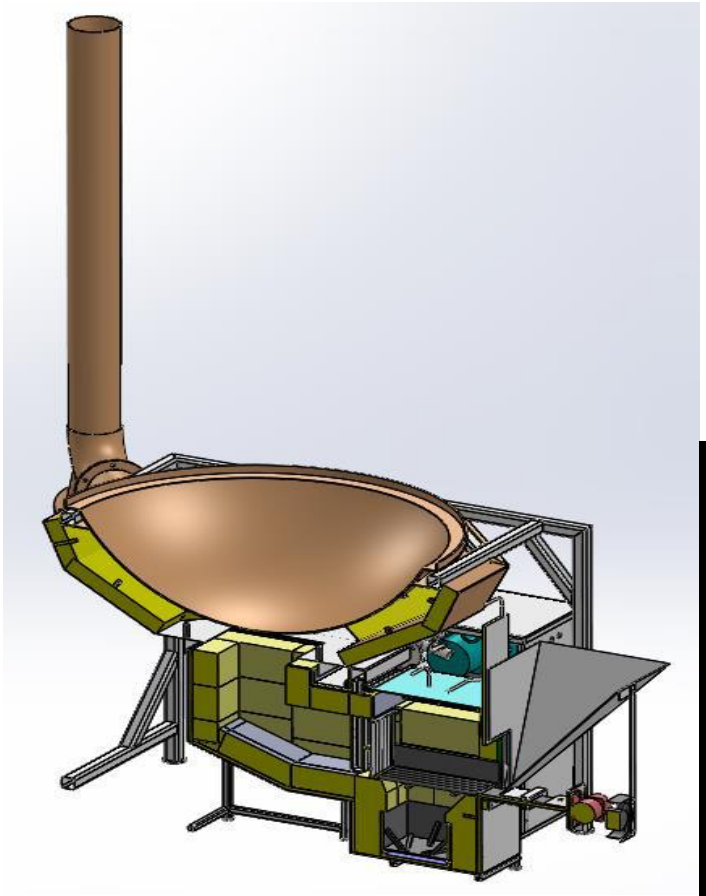
- Very light fuels need a bottom claw device to enable extraction of ash/char mix.
- Gentle movement of plate over which the fuel bed rests would be adequate to move the fuel towards the grate
- Many variants in combustion chamber design are possible. Strong limits on particulate emissions demand that the fuel flux across the combustion chamber cross section should not exceed 100 kg/m^{2}h (meaning superficial velocities through the chamber should be around 5 cm/s).

Higher Power systems



The 3.5 kg/h system with all the details shown. Note the 12 V, 12 W, battery based power supply to run the Sunon two-stage blower inside the power supply box, the locations of bottom and top air supply and the ash tray.

The FEPL built systems

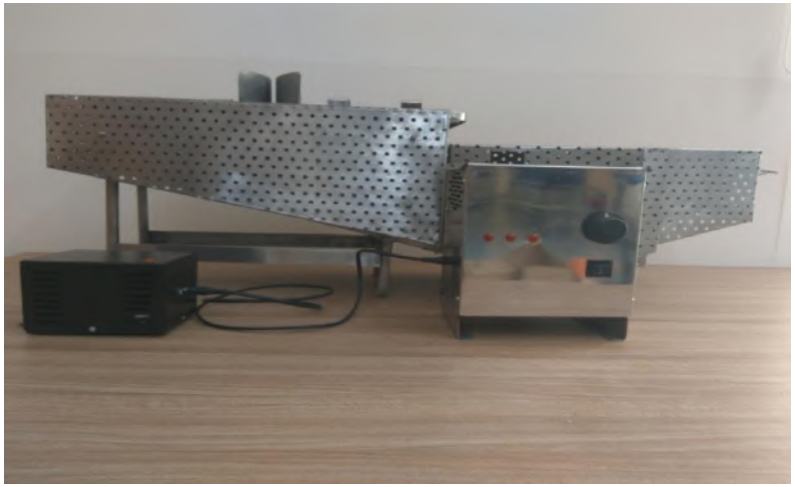


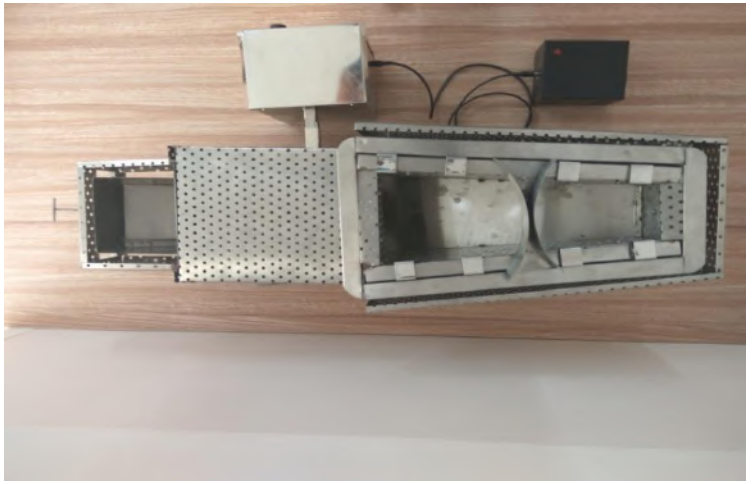
The 12 kg/h system built and tested at the factory at FEPL before shipment to a field location in Mumbai

Design modified later with moving grate to avoid ash fusion

Meeting low first cost demand for domestic stove.

- The two pan stove had all the desirable characteristics from a customer's view point, but the cost of the stove was still on the higher side for the rural population to afford…what is high? From the surveys, it appears that price less than Rs. 1000/- most desirable, Rs. 2000/- acceptable. Beyond that, one needs to conceive of financing schemes.
- Although there were financial schemes available, it was important to make an effort in changing the design, material used, and/or manufacturing processes to bring the cost to its minimum, beyond which one could expect economies of scale to take care.
- The price of the aesthetically good looking, wonderfully working, high efficiency and low emission system was Rs. 5800/- - way beyond the expectations.





Efforts to reduce the cost

- The Stainless Steel version had about 60 components that needed assembly involving high labour cost (skilled)
- When fire bricks were used to reduce cost, the weight shot up, reducing the efficiency as also the labour cost being high.
- Many other efforts at this time – were discarded after brief trials.
- Fortunately, a “new” (but really old) ceramic material named Perlite, composed of SiO_2 and Al_2O_3 was uncovered. This material in the form of powder (1 to 5 mm dia) was intended to be put integrated into cement – sand curing system. The ratios between perlite, cement and water were varied to get a good structurally good system to withstand combustion temperatures of 1100 C.
- For long life it needed a sheet steel outer casing or at least a frame.

The final AGNI-SAKHI model with perlite and MS frame

- The Agni-sakhi 1.2 to 13 kg/h two pan continuous combustion system was tested in about 200 house-holds by TIDE.
- Performance was considered good, and the production cost was Rs. 3000/-.
- At this production cost, definite need for financing arrangements were thought needed.
- Also the fuel supply chain was to be established.

- Around this time, a suggestion was made to revive the single pan combustion system to take account of first cost imperatives. Firewood or firewood like material could be an alternative
- This led to the VEBCOD design……..

Vertical Ejector Based Combustion Device

- The Vertical ejector based combustion device (VEBCOD) is a single pan stove that aims at using biomass over a wide range of densities, with limited sizing requirement and having simple construction with low production cost.
- It is compact, light weight, single pan ejector based low power system that uses a combination of HFI bricks and MS.
- The system has been standardized around the air supply that uses a 2W blower via jet through holes struts introduced into the combustion chamber with a velocities of 10 m/s to limit the particle carry over
- Stoves of different power levels (0.9 – 1.5 kg/h) have been built and test run or operationalized in field locations for tens of hours.
- The cost of production was brought down to Rs.2000 per system
- Further reduction in cost must occur with scale of production

The Final Design sent for Field Testing

0.9kg/hr design with an air supply to the bottom of the grate.

Higher power VEBCOD systems

A 15 kg/hr VEBCOD system in operation (Synergy pvt ltd)

A 3.5 kg/hr system

Summary

- Much progress has happened in Forced draft clean combustion systems over past fifteen years and in the last five years at FCRC.
- About 20 large biomass based combustion systems (3.5, 15, 50, and 150 kg/hr) in horizontal and vertical combustion modes have been commercialized and a few hundred 1kg/hr systems have been field tested.
- The efficiency, emission performance as well as functional acceptability of these systems have been found acceptable.
- In so far as the 1 kg/h system for domestic use is concerned, the challenging ***non-level playing ground*** created by Govt (by infusing subsidized LPG system) may call for better times even though meaningful and desired use in rural communities is a need.
- In the case of larger size systems, both HC3D and VEBCOD have a large number of applications. These are being capitalized upon by Mr. Ravi kumar (Harit Avani Industries) and Bidhan Loitingbam (SEES, Imphal). Now onwards, over to them……..

……Thank you.