Portable Wood / Biomass Stoves from Indian Institute of Science

(IPOBIS = Indian Institute of Science Portable Biomass Stoves)

Abstract:

A number of portable wood and biomass stoves have been designed, built and tested at Indian Institute of Science over the last decade. The fuels considered are firewood/tiny sticks/sawdust/other fine and pulverisable agro-residues like coir pith, bagasse, leafy residues and even dried urban waste in a well-defined manner. The aim of the design is to provide a combustion behavior close to what is obtainable in gas stoves, with the use of a blower of 1-50 W capacity for stoves delivering 3-50 kWth capacity. i.e., about 1 to 12 kg/hr of fuel consumption.

The aim of the design is to burn the solid residue with a facility to have some control on power, reduce emissions, maximize the efficiency of heat transfer into the vessel, minimum tending and low first cost. While it would be impossible to achieve all these features in a single design, particularly at low power levels, also including the ability of the stove to perform with loss of electricity. it is possible to generate designs that meet one or more of the objectives more significantly than others.

The document presents the designs of various stoves and methods of operation of each of them to get the best out of the design. It also provides drawings for fabrication and typical operational presentation of the system.

Introduction:

Many households in cities have LPG (Liquid Petroleum Gas) stoves. Normally these are provided with two burners of 1 and 3 kWth maximum capacity respectively, with operating efficiencies of about 65%. The wick-type kerosene stoves and the pressure-fed stoves are also of 1 - 3 kWth capacity with operating efficiencies of 60-65 %.

A variety of wood stoves of single, two and three pans have been conceived, designed, built and tested both in India and abroad. The best efficiency of commercially available single pan stoves that are available in India has been about 30 % (Mukunda et al 1988). Most of the single pan stoves designed so far use to a large extent the diffusive flame between air and fuel for combustion and to transfer heat directly to the vessel.

Stoves under consideration:

The stoves first discussed here are the stoves for use of firewood/sticks somewhat conventional in design, but aimed at enhancing the efficiency, requiring loading of the fuel periodically. Figure 1 shows the schematic of such a stove called SWOSTHEE (Single pan Wood Stoves of High Efficiency). Combustion is designed to occur over a grate: the height of the stove above the grate is limited to the height of the diffusion flame at the average power level so that hot gases, with temperature close to adiabatic temperature expected in a diffusion flame are obtained. Further a perforated cylindrical chamber around the flame is added so that the flame can draw air from several points, thus reducing the dependence for combustion on the airflow drawn from the fuel loading port, which may vary with charge loaded. The diameter of the perforated chamber is so chosen that it limits the length of the fuel pieces which in turn limits the power. Thus if the user tries to pack the fuel loading region, the peak power gets limited by the size of the fuel sticks on the grate which is equal to the diameter of the perforated cylinder.

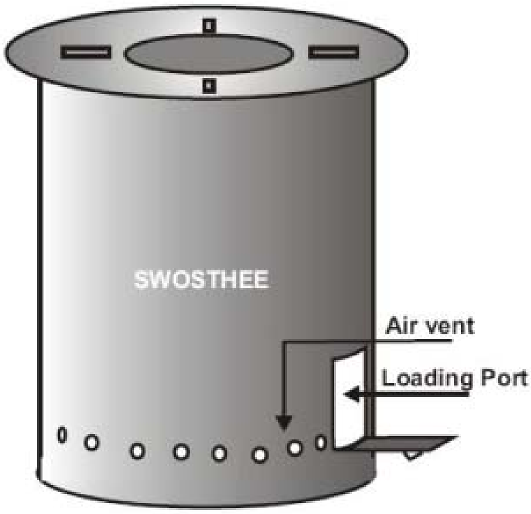


Fig 1 : Swosthee Stove

The hot burnt gases transfer the heat on to the cooking vessel by allowing the gases to flow between the vessel and a top plate. The convective heat transfer enhanced by suitably chosen passage width between the plate and the vessel helps in the higher levels of efficiency. Fundamental studies, both computational and experimental (Sangeeta et al, 1997 and Mukunda et al, 1990) have shown that getting as high a temperature of the burnt gases is essential for higher efficiency. It was determined that this is the single most important factor for limiting the water boiling efficiency to about 45 % in wood stoves with typical gas temperatures of 850 to 1000 C. It must be realised that liquid fuel based stoves like kerosene stoves give water boiling efficiencies of 65 % because the steady flame temperatures areas high as 1500 C. In the case of wood stoves, typical practical efficiencies are 30 to 40 % depending on the power level and the ratio of the exit diameter of the hot gas from the stove to the vessel size. The other principal reasons for lower efficiency lie in the restriction imposed by the vessel shape and size, very rarely recognized in stove design. Family cooking which typically calls for a power level of 3 to 5 kW is expected to allow cooking on vessels 200 to 400 mm diameter, either flat bottomed or curved.

Figure 2. Shows the typical vessels available in markets in India essentially meant for cooking.

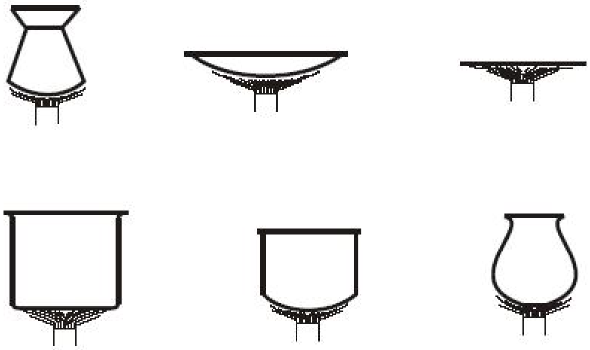


Fig 2 : Typical vessels used in India for cooking

Optimization of stove design for efficiency leads to a design with the ratio of vessel diameter to burner gas stream exit diameter of 2.5 or better. This choice leads to efficiencies better than 25 %. However, in many practical applications the nature and size of the vessel does limit the achievable efficiency. For instance, the choice of a curved vessel, prevalent in some rural societies limits the efficiency to about 20 %, even though the same stove in another environment using flat bottomed vessel leads to efficiencies in excess of 25 %. The outer shell made of thin metal sheet in the stove is of minor importance for the functionality of the stove. Increases of 1 - 2 % in efficiency can be obtained by providing a thin insulation on the inside of the cylindrical shell but this adds to the cost of the stove.

The width, height of the opening over the grate and the loading port area, all control the peak power of the stove by limiting the amount of fuel loaded onto the grate. Users - housewives generally - think that larger the flame implying higher fuel loading is an allowed practice for stove operation. Unfortunately, such a practice implies lot of sooting and loss in efficiency. Hence, it is important to recognize that a lower peak loading is desirable to obtain the same output with better efficiency. This is the reason for limiting the fuel loading on the grate. There have been demands from some stove users to relax this; but such an action goes counter to the objectives of the design.

Due to the above mentioned requirements, there are implications on the nature of the fuel. Large stocks of wood need to be cut into pieces for use.

Alternately one can use thinner cotton stock, corn stock, and other smaller fragments for the purpose - a feature that is user friendly for those who can recognize the benefits.

Figure 3 is the plot showing the efficiency of the stove as a function of the vessel size. Stoves of larger power level were designed and tested. They are not recommended for use since their efficiencies are about 25 % and are considered inadequate for stoves of this power level.

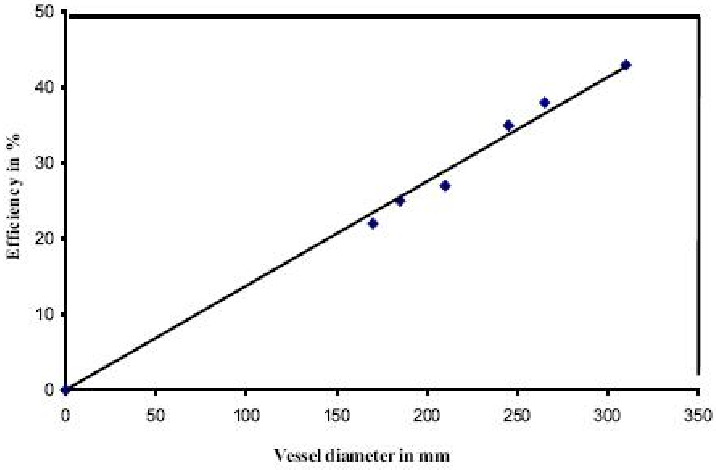


Fig 3 : Efficiency of stove as a function of vessel size

Pulverised Fuel Stoves

Pulverised fuels are several - sawdust, coconut coir pith, pulverised urban waste, leaf litter in urban environment which is considered waste (as distinct from those in villages, where it is considered as apart of humus; even here this view is correct to a limited extent). A typical sketch of this stove is shown in Fig. 4. These stoves have been in use in various parts of India or elsewhere. The systems considered are made of any waste cylindrical container with arbitrarily chosen dimensions for the height and core diameter of the fuel block inside the container. Some of these stoves take a long time to light up with heavy smoke during this period. There has been no serious scientific study on the system aimed at determining parameters that lead to good start up and steady combustion. These were dealt with in a study at the laboratory. The exploration in addition is towards other configurations to design the system for a given power and known burn time. One of the primary features distinguishing this design from SWOSTHEE is that with a given stove, the total energy delivered is fixed.Once lit, one has to allow all the energy to be expressed. While it may not be impossible to design some quenching device, it would be complex and also adding to the cost. As such this class of stoves can be called fire and forget.

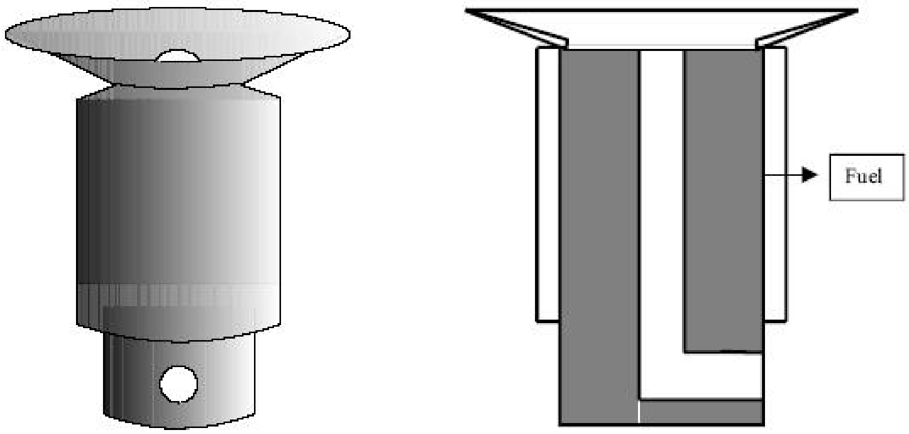


Fig 4 : Pulverised Fuel Stove

The advantage is that for the housewife, cooking can be managed as a chore and as being part of the other activities she may be compelled to be involved in. For cooking purposes, typical operational time is taken as one and a half hour and power level as 3 kWth. For other semi-industrial purposes, like water boiling in silk industries (for cooking the cocoons), one can use this device for operational duration as large as 5 to 10 hours continuously.

Design Procedure

The design of the stove is based on the power level P (in kW) and the burn time t b required. The burn time and the power level can be related to the geometry of the stove using the equations given below.

$$d_o - d_p = 45\, t_b^{0.885}$$

$$P = 2.4 \times 10^{-4} d_p^{1.75} d_o^{0.5}$$

$$h \sim 5.5\, d_o$$

where do, dp, and h are as indicated in figure 5. Figure 6 shows the stove design chart for various power levels and burn time.

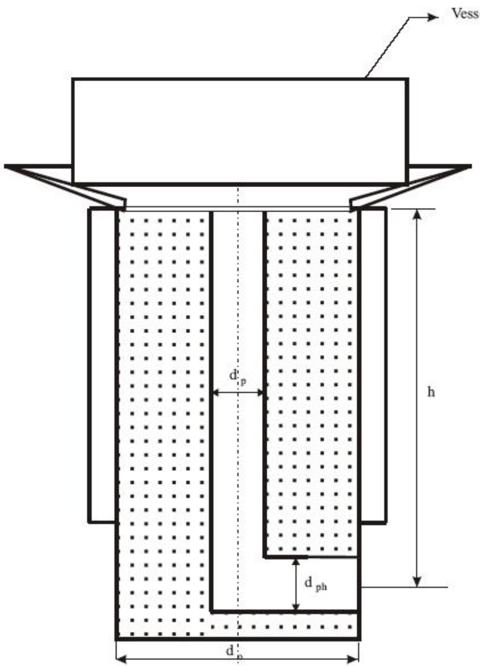


Fig 5 : Design Specifications of Pulverised fuel stove

[d o = Port Diameter , d ph = Port diameter on horizontal leg (usually equal to d p)
d p = Outer diameter of fuel block , h = height of fuel block]

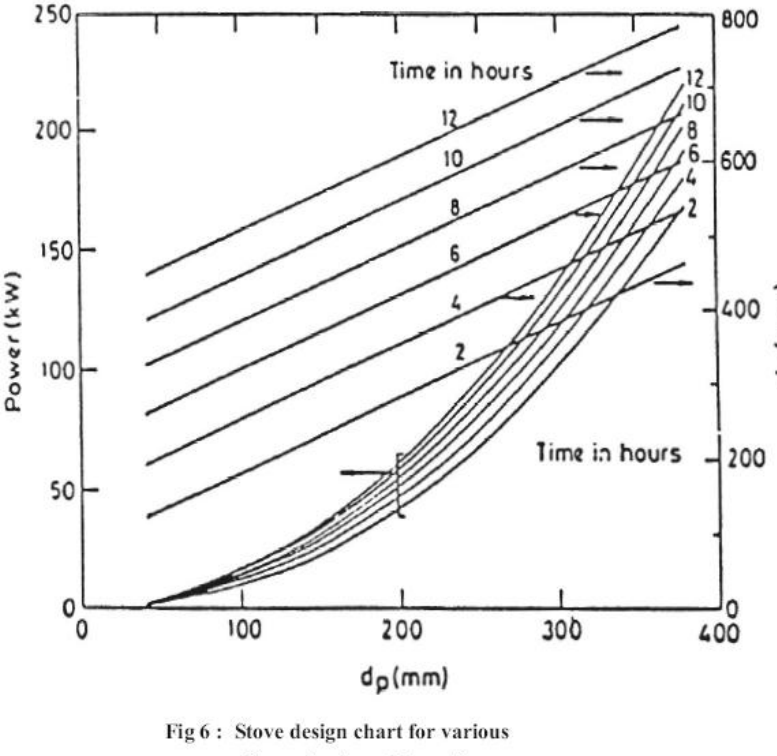


Fig 6 : Stove design chart for various Power levels and burn time

[Note : To get the value of d_p and d_o , project the required power level to the burn time and then project downwards to get the value of d_p in mm. For d_o , project the value of d_p on to the straight lines representing burn time and get corresponding value of d_o]

Gasifier Stoves

Dr. Thomas Reed (Golden, Colorado) is credited with the principles associated with this stove. This stove functions on ' fire and forget ' principle. It has been demonstrated by Dr. Reed for wood chips. The essential principle is that by using reverse downdraft principle, one can generate combustible gases much like in a typical downdraft gasifier. These gases are burnt above the fuel char bed with additional air to produce intense combustion. He has demonstrated that a 2 Watt blower can deliver clean thermal energy of about 3 kWth. Fig 7 shows a schematic sketch of a gasifier stove.

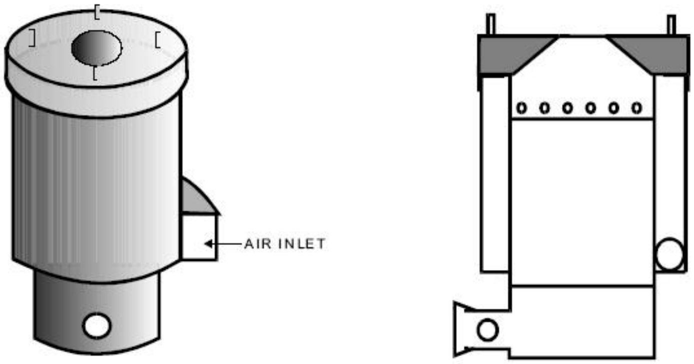


Fig 7 : Gasifier Stove

Adaptability of Gasifier Stoves

In the context of demands from developing countries, it is important to examine how one can create options in which unavailability of electricity is taken care; how the occasional availability of electricity can be used to enhance the quality of combustion; how to arrange combustion of pulverised fuels in the same stove design and in doing all these how to keep stove initial cost down.

A typical cook stove burns 1.5 to 2 kg bio mass - wood chips/sticks/coconut shell pieces/pieces of husk/about 10 % pulverised material of any bio residue in about one and a half to two hours leading to a power level of 3.5 to 4 kWth for 75 % of the burn time. The remaining char burns up subsequently, albeit at a lower power level. The start up method is in contradiction to tradition. The bio mass is filled into the stove till a location just below the air entry zone. The filling technique must be such as to uniformly load the material. Then one can sprinkle kerosene or alcohol preferably, if available. The system can then be ignited. After a minute during which time the combustion process gets stabilized, air from the blower can be turned on. This makes the combustion process complete in a small volume and permits top cover to be placed over which cooking vessel can be placed. The most vital point is that if one uses alcohol, one can notice that the flame from the stove is comparable to that from a gas stove. If the cooking requirement is complete even before the stove has stopped functioning, the flame can be smothered by insulation blanket and covering of the top completely.

If the blower cannot be operated because of lack of electricity, the combustion of the gases takes more volume. This implies that when cooking vessel is placed on the stove, the flame will appear sooty on occasions in the early part of the stove operation. After about ten minutes by which time the inner wall would have acquired heat for pumping air for combustion through free convection, the quality of the flame is much better, perhaps, not as good as one would get with blower on. The control of the air through the fuel section will alter the power level. Increasing the airflow through the fuel bed will raise the power level substantially. Closing it completely will bring it to a minimum.

This stove can be converted to operate on pulverized fuel largely; some amount of solid stock can also be included as long as it gets embedded into the pulverised fuel block. The method is shown in Figure 8. Typical tools are PVC tubes of appropriate diameter and length. These can be placed into the container after lifting the grate structure. Then one can fill in the pulverized material along with solid stock and tamped to become a rigid framework. The PVC tubes are then taken out and the stove lit both at the bottom and the top zone by sprinkling some liquid fuel both into the bottom and top zones. This will ensure complete combustion of volatiles in the system right from the beginning.

Figures 9,10,11,12 show geometric drawings for these to be manufactured. The component that ensures good combustion is the blower. Such blowers of low power level are usually unavailable and if available are expensive. Efforts are being made at IISc to permit mass manufacture so that individual costs can be brought down.

A comparative statement of the performance of various stoves is presented in Tables 1 and 2. This will help in deciding the choice of the stove for specific applications.

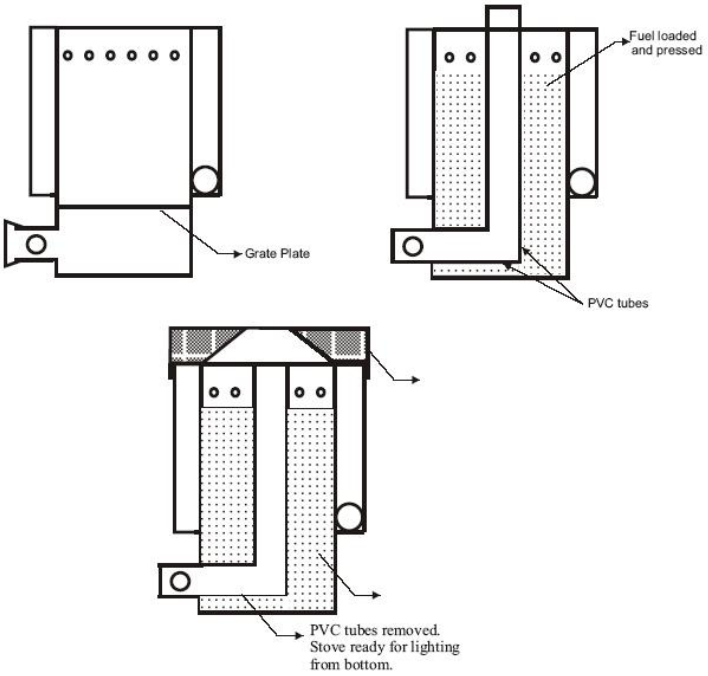


Fig 8 : Conversion of Gasifier stove to Pulverised fuel stove

Step 1: Remove the top cover and the grate plate

Step2 : Place the two PVC tubes, load the fuel and press it so that it stays firm.

Step 3: Remove the PVC tubes and replace the top cover.
Light the stove from the bottom.

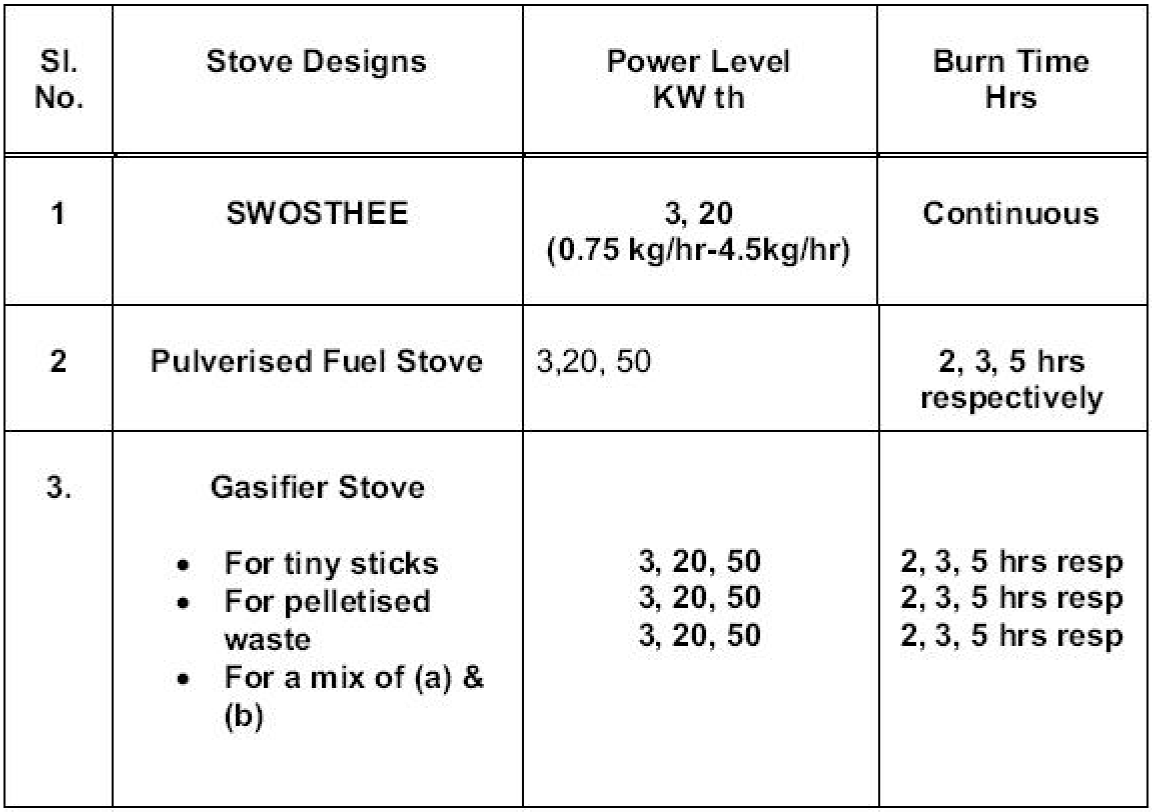
Gasifier Stove(3-4 kWth)

Industrial scale Gasifier stove(~25kWth)

Swosthee stove(2- 3kWth)

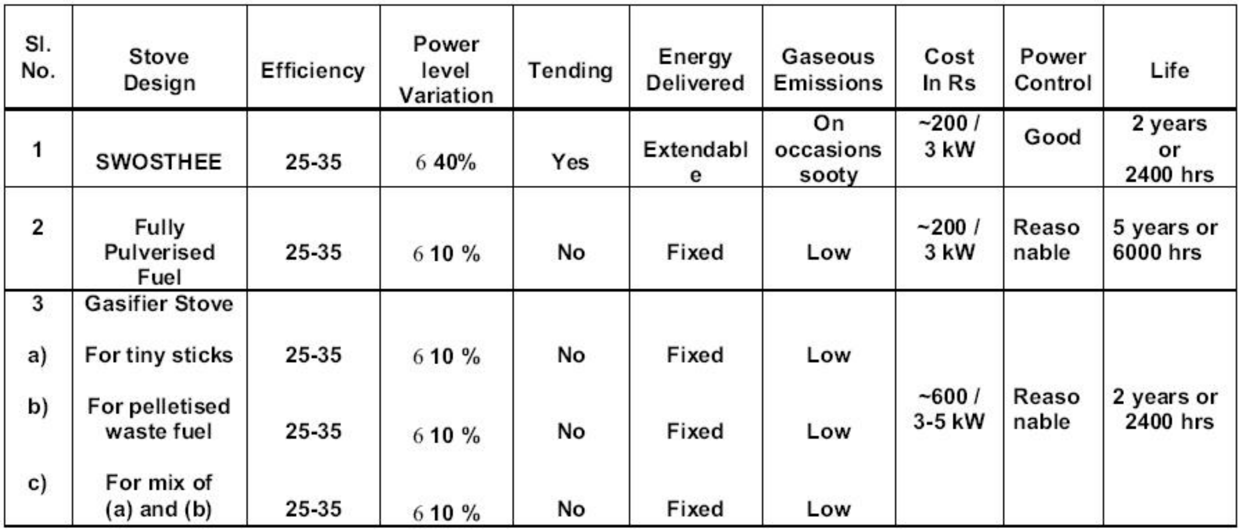
Photographs of various stoves

Table 1: Comparison of duty cycles of various stove designs

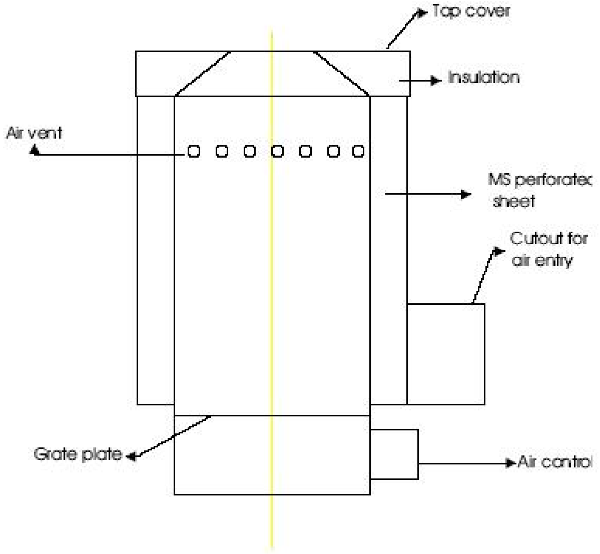


Sl. No.	Stove Designs	Power Level KW th	Burn Time Hrs
1	SWOSTHEE	3, 20 (0.75 kg/hr-4.5kg/hr)	Continuous
2	Pulverised Fuel Stove	3,20, 50	2, 3, 5 hrs respectively
3.	Gasifier Stove • For tiny sticks • For pelletised waste • For a mix of (a) & (b)	 3, 20, 50 3, 20, 50 3, 20, 50	 2, 3, 5 hrs resp 2, 3, 5 hrs resp 2, 3, 5 hrs resp

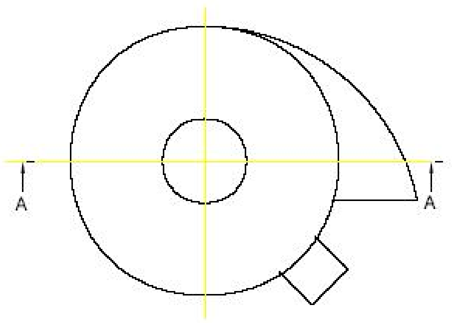
Table 2: Comparison of performance of various stove designs



Sl. No.	Stove Design	Efficiency	Power level Variation	Tending	Energy Delivered	Gaseous Emissions	Cost In Rs	Power Control	Life
1	SWOSTHEE	25-35	6 40%	Yes	Extendable	On occasions sooty	~200 / 3 kW	Good	2 years or 2400 hrs
2	Fully Pulverised Fuel	25-35	6 10 %	No	Fixed	Low	~200 / 3 kW	Reasonable	5 years or 6000 hrs
3	Gasifier Stove						~600 / 3-5 kW	Reasonable	2 years or 2400 hrs
a)	For tiny sticks	25-35	6 10 %	No	Fixed	Low			
b)	For pelletised waste fuel	25-35	6 10 %	No	Fixed	Low			
c)	For mix of (a) and (b)	25-35	6 10 %	No	Fixed	Low			

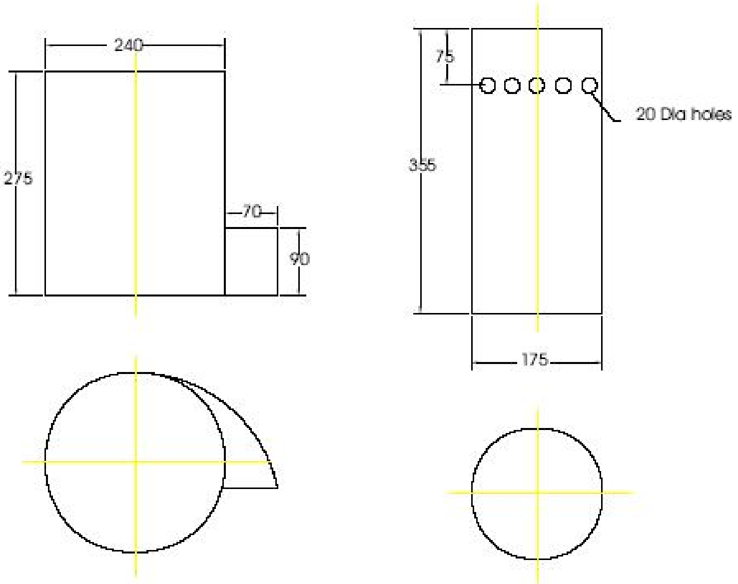


Elevation (Section at A-A)



Plan

Fig 9 : Assembled drawing of Gasifier stove

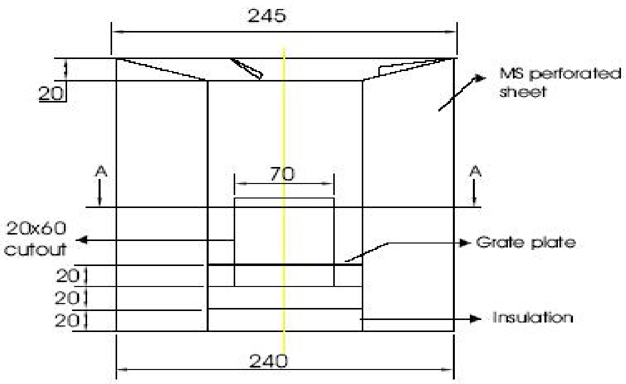


Outer shell

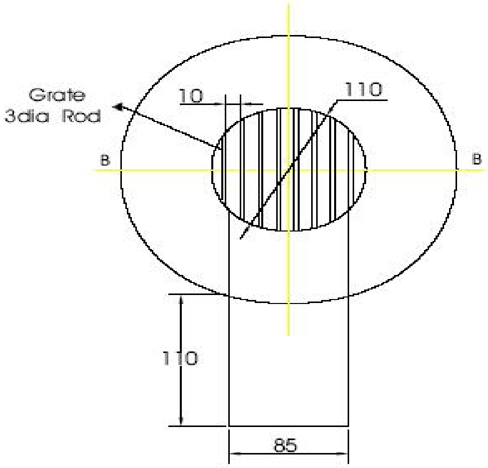
Inner shell

Note: 1) Material of stove : MS
2) All Dimensions in mm
3) Not to scale.

Fig 10 : Part drawings of Gasifier stove



Elevation at section B-B



Plan at section A-A

Fig 12 : Assembled drawing of Swosthee stove

References:

1) Mukunda .H.S., Shrinivasa .U., and Dasappa.S (1988)
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3) Reed, T. B., and Larson, R., A wood-gas stove for developing countries, pp 985-993, Developments in thermochemical conversion, Blackies and professional, 1997

4) Kohli .S, Ph.D. Thesis, Indian Institute of Science, Bangalore,1992.
"Buoyancy – induced flow and Heat transfer in Bio mass stoves.