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DESIGN AND DEVELOPMENT OF A RICE HULL-BIOMASS COOKSTOVE

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ABSTRACT

Biofuels from biomass abound from agricultural produce and waste, and from forestry products and aquatic plants. Rice hull from rice biomass is a milling by-product which can be used as fuel for a variety of purposes including household cooking. Similarly, coconut shell and husk are by-products and are used as biofuels. Previous studies on rice hull stoves were reviewed. A set of criteria was generated in order to incorporate desirable features for the new rice hull-biomass stove design. Work to improve existing rice hull stoves focused on minimizing attention required to maintain an effective flame, which is normally done by disturbing the fuel bed.

The implementation of the combined center-tube, conical grate, and nozzle stove principles led to the development of a novel rice hull-biomass cookstove capable of using a variety of biofuels such as sawdust, wood chips, coconut shell and husk. Tests were conducted to evaluate the rice hull-biomass stove and the conical grate rice hull stove. Heat utilization efficiency of up to 20% translates to more fuel available for cooking.

INTRODUCTION

Alternative renewable energy sources like biomass can help relieve the pressure on forest resources. Biomass includes forest residues, agricultural crops and waste, aquatic plants and municipal waste. These can be converted to biofuels by chipping or cutting to particulate size for direct combustion applications. Rice hull, the outer covering layer of the rice grain, is normally considered an agricultural waste. It readily comes in particulate form, and further size reduction is not needed to attain the easy-firing characteristics. The concave or boat-like shape of the rice hull creates a porous mass in bulk, entrapping air which is essential in the combustion process.

A PNOC study as cited by Capareda (1992) estimated the total biomass from agricultural wastes and forestry as 41 M metric tons (Table 1). At a low heating value of 10 MJ/kg, this can provide 88.3 MJ of energy per household per day for 9 million rural households. Daily cooking tasks normally require about 3 MJ daily, so that a stove with only 3% heat utilization efficiency (HUE) has enough energy to spare. Open fire cooking using wood has 8% HUE. As a renewable energy source, biomass can contribute to our efforts to gain independence from conventional household cooking energy sources such as LPG and kerosene.

Rice biomass. Rice hull is a rice milling by-product. It often causes disposal problems forcing millers to pay contractors to remove the hulls. The smoke from burning rice hull dumps causes irritation and visibility problems which sometimes caused highway accidents. The estimated rice hull output in the Philippines is about 2 million tons, which is roughly equivalent to 3×10^{10} MJ, about 8333 MWh, or enough fuel to power about 76 2-MW generating units. In 1984, the Philippine Development Report, recorded rice hull utilization at 0.7 million barrels fuel oil equivalent. This provided 0.8% of the energy demanded. This utilization level is about 16% of the total rice hull produced. Two million tons rice hull can provide about 5 percent of the total national energy demand.

Table 1

Agricultural wastes production in the Philippines (Extracts from Capareda, 1992).

Residue	Estimated Annual Production (MT)
Bagasse	2,063,470
Coconut Husks	5,575,030
Coconut Shell	2,508.770
Rice hulls	1,868,000
Rice straws	18,679,980
Corn cobs	1,151,580
Corn stalks	4,145,620
Logging wastes	2,228,270
Sawmill wastes	1,507,040
Veneer/plywood wastes	1,569,890
Total Agricultural wastes	**41,297,650**

Rice hulls have been largely ignored as a domestic cooking fuel because they are difficult to burn and are bulky. Traditional rice hull stoves generate smoke and require constant fiddling to keep them burning. New stove designs should overcome these shortcomings. If widely adopted, a suitable rice hull-biomass stove can considerably reduce the pressure on forests which are plundered for firewood for household cooking fuel.

The heat value of one kilogram rice hull is about 11 to 16 MJ, enough to evaporate 30 L water from 25°C. Thus the hulls from 1 kg paddy, about 200 g has heat value of 3 MJ should be sufficient to cook about 1 kg rice, since only 0.33 MJ are needed (Table 2). Heat balances for some cooking stoves are shown in Table 3. It shows that even the most modern biomass stoves would require at least three times the amount of fuel actually needed. Normal cooking tasks require as much as ten times the theoretical fuel requirement.

Coconut biomass. The Philippines has an estimated 290 M bearing coconut trees, or about 4 coconut trees per individual. Even at the low yield level of 39 nuts/tree/year, these can provide a year supply of coconut shells and husks for 9 M rural household at consumption level of 3 nuts/day.

Each nut will give up to 115 g of coconut shell and up to 224 g of coconut husk. Coconut shell has a heating value of 20.1 MJ/kg, while coconut husk has heating value of 18.1

MJ/kg. Combining these with 200 g rice hull from one kg paddy at 13 MJ/kg heating value, will provide us with up to 9 MJ of energy, and should be sufficient for a single session household cooking.

Table 2.
Energy Required for Cooking
(From *Biomass Stoves (1987) p. 28* by Samuel F. Baldwin)

Food	Specific heat (KJ/kg°C)	Temp. Change (°C)	Energy Req'd for Chemical Reactions (KJ/kg)	Total Cooking Energy (KJ/kg)	Wood Equiv. per Kg Food** (g)
Rice	1.76 - 1.84	80	172	330*	18
Flour	1.80 - 1.88	80	172	330*	18
Lentils	1.84	80	172	330*	18
Meat	2.01 - 3.89	80	---	160 - 310	9 - 17
Potatoes	3.51	80	---	280	16
Vegetables	3.89	80	---	310	17

* This includes sufficient water for cooking but none for evaporation
** For wood with calorific value of 18 MJ/kg

Table 3
Heat balances in cooking stoves
(Summarized from *Biomass Stoves (1987) p. 29* by Samuel F. Baldwin)

Stove type	**Final Energy Balance**	
	Gains (%) (heat utilization efficiency)	Losses (%) (unproductive heat)
1. Traditional open fire	8	92
2. Thai charcoal stove	3.1	96.9
3. Two pot uninsulated metal wood stove with chimney	27.9	72.1
4. Two-pot massive wood stove with chimney,	15.4	84.6
5. Three-pot massive wood stove with chimney	6	94

Projected impact of people using rice hull-biomass stoves

Socio-economic impact. At the family level, the use of rice hull-biomass stove can reduce or eliminate the time allocated for gathering firewood. Foraging for fuelwood, usually done by women may require walking 12 km or spending at least 3 hours daily. A 25-kg bag rice hull may be collected only once at a rice mill using only 3-4 hrs weekly. Therefore, 17-18 hours are freed for other gainful activities such as a part-time job, or simply for child-rearing.

A rice hull-biomass stove is easier to ignite than a firewood or charcoal stove. When air supply is sufficient it emits less smoke. Less smoke inhalation means less respiratory problems. Air pollution in the kitchen and in the environment as a whole, is likewise lessened.

At the community level, stove-making gives opportunities for entrepreneurs to increase industry output, creates more jobs, and other supportive economic activity.

Environmental impact. The use of rice hull-biomass cookstove will reduce cutting of trees and or harvesting fuelwood stands. Cutting trees for fuelwood accounts for 50% of deforestation. Based on estimates, a 5-ton rice harvest can augment the fuelwood supply deficit, a rough equivalence of 2-ha ricefarm for 1-ha fuelwood forest (see Appendix). The strategy is augmentation. At the national level it is not possible to fully shift to rice hull alone as household cooking fuel since current rice hull production cannot satisfy the demand. However a cookstove which can utilize a variety of biofuels may enable a full shift to biomass as fuel for household cooking.

Using rice hull instead of dried dung as cooking fuel increases availability of fertilizer and translates to increased soil fertility, more crops can be produced.

Rice hull stove users will contribute to solving rice hull disposal problems which in some places have caused accidents, destroyed fishponds, and clogged streams and waterways.

Objective

The main objective of this activity is to design and develop a suitable cookstove which uses rice hull or biomass for fuel. Such cookstove must satisfy the following criteria: should be easy to fire, should emit less smoke, require minimum user attention, should be a simple design.

2.0 BIOMASS STOVES

Rice hull stoves. Most biomass stoves are either woodburning or charcoal-fed. Adaptations of these stoves for rice hull have been attempted by several authors.

In 1976, Singh & Garg, reported the design and construction of a simple rice-husk stove. The stove is jar-shaped and is made from 3 mm mild steel plate. The inside body is cylindrical with a trapezoidal bottom portion made from cast iron. They reported fuel consumption of from 2 - 3 kg/hr, depending upon the amount of airflow. The flame was also reported as smokeless, except during firing. No mention was made of the amount of attention required nor of its thermal efficiency. Fabrication of this stove will be difficult because, small welding shops are usually not equipped with iron casting accessories.

In Sri Lanka, Adhikarinayaka & Palipane (1982) reported on a traditional rice husk clay stove which they improved using a mild steel cylinder with an inclined bottom plate and a center opening as the grate (Figure 1). To fire the stove, a burning firewood stick was inserted through the inclined air inlet duct to the center. They were able to boil 4 L of water in 21 minutes using 600 g ricehull. The increased efficiency was probably due to the firewood-rice hull combination.

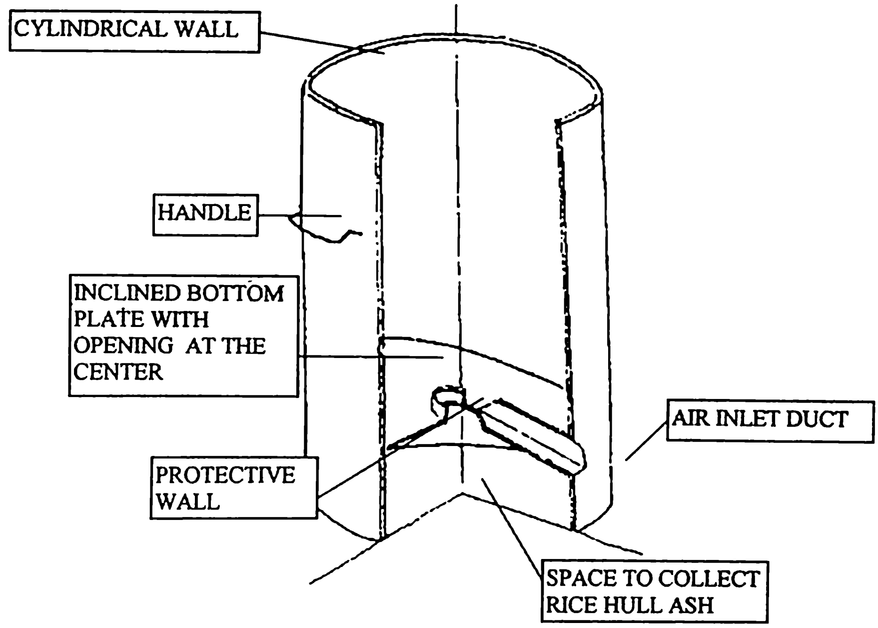

Figure 1. Improved paddy husk fired stove in Sri Lanka (Adhikarinayaka & Palipane, 1982).

In 1986, a rice husk stove from Indonesia was reported by Prof. Herman Johannes (RAPA Bulletin, 1986/2). The stove can be made from clay or metal, and is composed of three cones (Fig. 2). Cone A serves as hopper and its lower portion as combustion zone. Cone B becomes incandescent and scorches rice husk in contact with it. Cone C acts as a cover to direct smoke to be sucked into the Cone B to burn off. By pulling and pushing a ring made from wire placed on Cone A's floor, ash falls into the ash pot and husk descends into the hopper. It was not clear whether the stove was used for household cooking. No tests were reported.

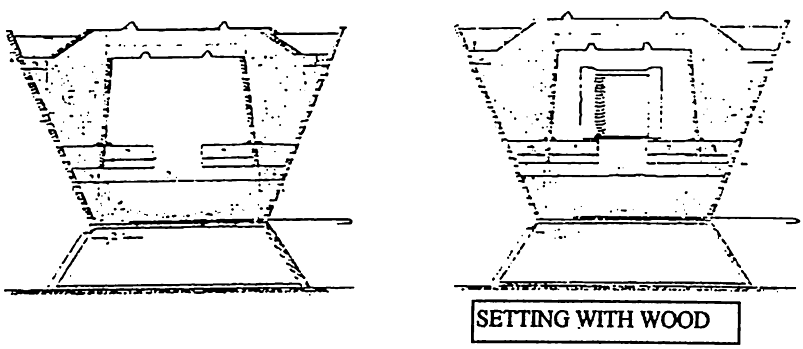

Figure 2. Triple cone rice husk stove, as reported in Indonesia (Johannes, 1986).

In 1992, a Vietnamese scholar, Phan Hieu Hien introduced a rice hull stove at IRRI. It features a conical grate with perforations at the base and extending upwards to form the hopper (Figure 3). The combustion zone is isolated by a center tube which also acts as insulator by creating an air space by means of a conical frustum fixed on the inner part of the center tube. The ashport is made up of a circular plate fixed to the grate with a gap specified as not less than 25 mm. Constant attention by manipulating the fuel bed is needed to maintain the flame.

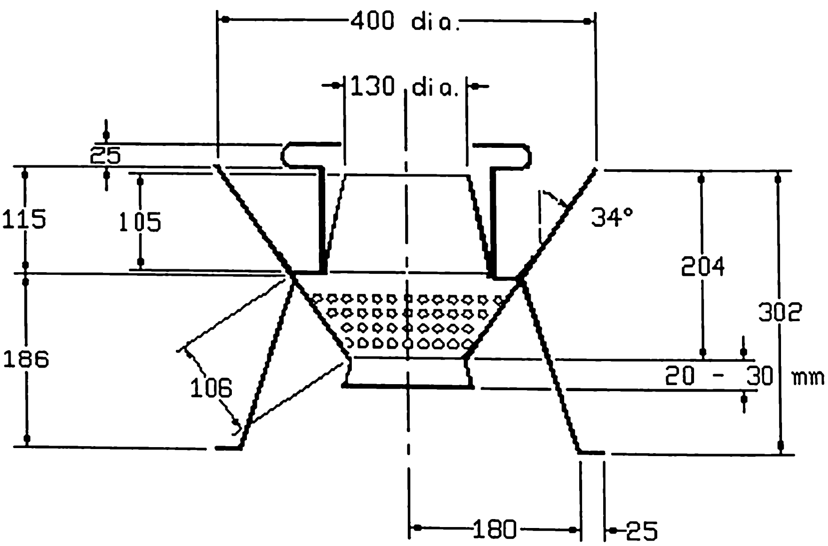

Figure 3. Conical grate stove called "*Lo trau*", from Vietnam (Hien, 1992).

Stove design at IRRI. Research on the utilization of rice hull has been concentrated on its use as fuel for the IRRI step-grate furnace, e.g. drying purposes. During the IRRI-IDRC project (1984-88), a rice hull carbonizer was designed for the production of rice hull briquettes. A special stove for the briquette was designed . It was made up of a big earthen flower pot with sand-cement mixture as lining. A cylindrical opening was provided, and a stopper on the bottom to hold the briquette in place. The bottom portion was open to allow air to circulate. In 1991, Vassallo, recognizing some problems with briquettes as fuel, recommended that research be focused on direct rice hull utilization, rice hull stove testing, and modification of existing designs.

Nozzle Stove. This stove uses a nozzle to accelerate convection currents generated by the combustion bed. Increasing convective heat transfer to the pot is the single most important way to increase the thermal efficiency of a woodburning stove. In his book, he categorized biomass or cooking stoves (with reference to convective heat transfer) into three fundamental types. Generically he termed these stove types as multipot, channel, and nozzle.

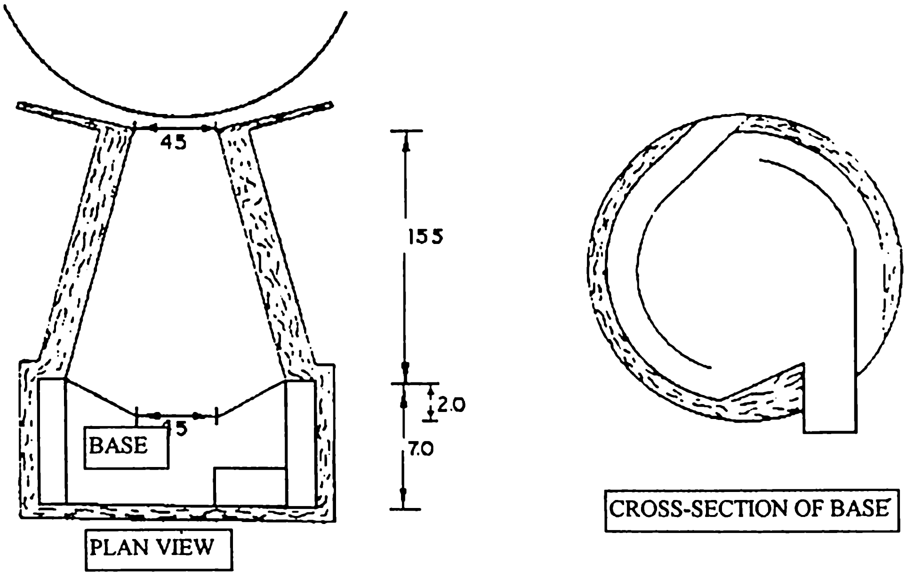

Figure 4. Nozzle stove, from India (Baldwin, 1987).

He described the principle of nozzle stove (Figure 4) as follows: *"For nozzle stoves, to increase convective heat transfer, the gas is accelerated up the height and narrowing combustion chamber and forced through a narrow channel over the pot. Emissions are reduced by bringing fresh air in at an angle to the combustion chamber, causing swirl and improving mixing of air with volatiles; by placing the baffle (5-7 cm) above the fuel bed to generate recirculation zones and thus improve combustion; and by providing a high combustion zone to allow completion of combustion".*

3.0 METHODOLOGY

3.1 Design considerations

Design criteria for rice hull stove. Prior to the design work, a set of criteria was formulated as desirable of a rice hull stove. The criteria include the following features: easy firing, low smoke level, low user attendance, low fabrication cost, and simplicity.

Easy firing. The stove should be started rapidly using a minimum of combustible materials, preferably pieces of paper. No additives must be used such as wood, kerosene or paraffin. The flame should develop as fast as possible and should be maintained within a reasonable time period, or must be able to boil 1 L of water in the shortest time possible.

Low smoke level. When fired, the stove must not emit excessive smoke to the discomfort of the operator. Low smoke level should indicate a high combustion efficiency, a desirable stove characteristic.

Low user attendance. Upon firing, the stove must require minimum attention from the cook to maintain a usable flame. This means the stove must have less adjustments and need the least manipulations in order for the user to cook properly.

Low fabrication cost. The stove should be made of materials that are readily available and using minimum of tools. Low fabrication cost will reflect directly on the stove selling price.

Simple design. The design must be easily comprehended to attract fabricators and manufacturers, as well as users to produce the stove.

3.2 Theoretical considerations

Combustion process. The combustion of biomass is simply expressed by the single equation (Williams et al., 1983)

$$C + O_2 \rightarrow CO_2$$

The combustion process may be envisioned as a sequence of three different types of chemical reactions: pyrolysis, reduction, and oxidation. These occur in zones that have different locations in furnaces and even in stoves. They are difficult to distinguish from each other, as boundaries are not clearly defined.

The first step in biomass combustion is pyrolysis, or distillation. In the pyrolysis zone, heat which is generated by the oxidation process drives off water from the fuel and breaks down some of the fuel constituents which contain large amounts of hydrogen and oxygen. Pyrolysis produces a complex mixture of large long chain hydrocarbons as well as other smaller hydrocarbons. As hydrocarbons vaporize, the fuel is reduced to char which is the basis for the reduction reactions.

The char being surrounded at first by a low oxygen environment undergoes a partial combustion and reduction process in which the following chemical reactions predominate:

$$\begin{aligned} 2C + O_2 &\rightarrow 2CO \\ C + H_2O &\rightarrow CO + H_2 \\ C + 2H_2 &\rightarrow CH_4 \\ CO + H_2O &\rightarrow CO_2 + H_2 \end{aligned}$$

These reactions proceed at rates which are dependent upon high temperatures, availability of oxygen and water, and the relative amounts of carbon and hydrogen in the fuel. The products of the reduction process include carbon monoxide, hydrogen, and methane. These three gases are the fuel for the oxidation reactions.

Upon reaching a zone where oxygen is available in sufficient quantities, the carbon monoxide, methane and hydrogen produced by the reduction process undergo oxidation which completes combustion. The pertinent reactions are:

$$2CO + O_2 \rightarrow 2CO_2$$
$$2H_2 + 2O_2 \rightarrow 2H_2O$$
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

These three reactions are highly exothermic and account for most of the heat generated.

Stove grate area. Grate area determines the amount of fuel reacting in the combustion zone. This may be expressed as a variation of the generalized heat equation of the form

$$Q = m\, c_p\, (T_2 - T_1) ;$$

and/or

$$Q = \rho\ (A \times L)\ H_v ;$$

where Q = Heat required or heat available
m = mass of heat sink
c_p = specific heat of sink
$(T_2 - T_1)$ = Temperature differential
ρ = density of biomass fuel
A = stove grate area
L = height or width of fuel mass
H_v = heating value of fuel

Heat transfer. Heat generated is transferred from the source to the sink, in this case from the stove to the cooking pot. Heat transfer can happen by conduction, convection, and radiation. Detailed discussion of these topics are involved, however these factors must be considered in order for a stove to attain enhanced heat utilization.

Some studies indicate that nozzle stoves attain increased heat utilization efficiency because of higher air velocities that enable the boundary layer to be dislodged near the surface of the bottom of the cooking pot. By removing the boundary layer, resistance to heat transfer is reduced.

Physical properties of rice hull and/or biomass material should be considered. Rice hull is a good insulator, and this attribute can be used to isolate the combustion nozzle and reduce unwanted radial heat dissipation or radiation.

3.3 Design of an improved rice hull-biomass cookstove

Conical grate stoves consists of the hopper containing the rice hulls which also serves as the pre-heating zone. Extending to a lower perforated portion of the conical hopper is the combustion zone, and the gap between the grate and the fixed circular plate that holds rice hulls from falling, is the ashport. The cylinder placed centered on the hopper creates a combustion chamber, and is insulated from ricehulls by placing a frustum made from mild steel plate. This cylinder also supports the cooking pot by means of round bar brackets. This configuration was found desirable for a rice hull/biomass stove in view of the ease of fuel loading brought about by a conical hopper.

To improve the combustion process, excess air is usually provided. This is implemented by making a wider grate area that will provide more air circulation. The combustion zone was made from black iron sheet.

Using the nozzle stove principle, a center frustum was designed to act as the nozzle. The nozzle dimensions were dictated primarily by the minimum dimensions that will allow unimpeded downward flow of rice hulls from the hopper, while at the same time allow for a maximum area for the initial firing of the stove. The top nozzle diameter was adjusted so that paper or firing material can be dropped into the combustion bed. To simplify further the stove design, the pot holder brackets were fixed into the hopper, with the center frustum in turn fixed to the same brackets.

A conical ashport was selected to aid in downward ejection of the ash. Since the ashport also holds rice hull from falling while at the same time acting as supplementary grate area, this dual function is made possible by a spring retainer. A spring retainer also provides for rapid termination of flame by forcing the ashport downwards and unloading the rice hulls.

3.4 Firing tests using pieces of paper and firing rice hull, coconut shell, coconut husk and saw dust.

The proper amount of paper to start the stove was determined by using approximately A4, A3, A2 sizes of scrap paper or newsprint material. These paper sizes correspond to weight equivalents of 2.5 g, 5.0 g, 10 g, respectively. Rice hull alone, rice hull-sawdust mixture, wood shavings alone, rice hull-coconut shell combination, rice hull-coconut husk combination were used in the firing tests. Coconut shells were cracked to size about 15 x 15 mm, coconut husk was cut into sizes 10 x 10 x 20 mm. The quality of the flame was observed with respect to each fuel. The presence of smoke was also noted.

3.5 Boiling test between a conical grate stove (*"Lo Trau"*) and the improved rice hull-biomass stove

A comparative boiling test was conducted for the "Lo Trau" and the improved rice hull/biomass cookstove stove. The procedure consists of boiling 1 L water using two equivalent cooking pot, and using the same amount of rice hull. The stoves were fired simultaneously and the pots placed on the stove. Water temperatures were monitored using thermocouples and readings taken every thirty seconds.

3.6 Rice hull consumption of improved stove

By using a digital weighing scale, rice hull consumption of the improved stove was monitored. The stove was fixed on top of the scale, then the weighing scale adjusted for zero reading. Readings were taken every thirty seconds. Two sets of trials were conducted, one set without agitation and one set normal operation, based on flame maintenance, by ejecting ash while simultaneously loading fresh hulls for combustion.

4.0 RESULTS AND DISCUSSION

4.1 Firing tests of stove

Ten grams of paper or newsprint material was found to be sufficient to start the stove. Rice hull alone provided a sustained flame up to 7 minutes without agitation of the fuel bed. Loading fuel in a layer arrangement was done by first putting rice hull up to three-fourths of the combustion cone, then load the desired layer of coconut shell or husk up to 50-mm thick. Layer-arrangement of biomass fuel (Figure 5), with rice hull as base material, proved effective in sustaining the flame for more than 10 minutes. Sawdust mixed with rice hulls at 1:1 ratio by volume, gave a more yellowish flame, which was sustained for about 10 minutes without agitation of the fuel bed. Using sawdust, partially burned fuel mixture has more tendency to cake which impeded fuel downward flow. Sustained flame of up to 25 minutes was possible using rice hull-coconut shell layers combination. Tolerable presence of smoke was observed during the tests.

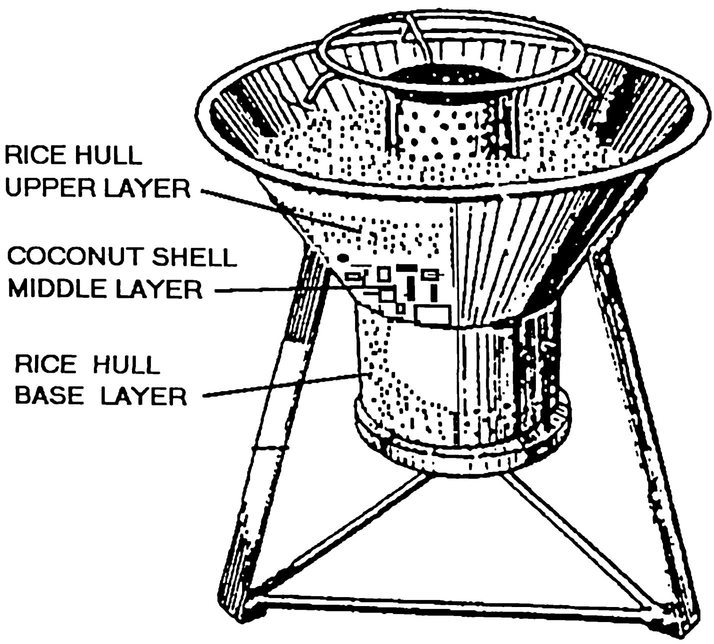

Figure 5. Layer arrangement of fuel bed

4.2 Boiling test

Boiling tests results, established the advantage of the improved stove in terms of the time required to boil 1 liter of water. Using the improved stove 1 L water boiled within 5 minutes of start-up (Fig. 6), as compared to the "Lo Trau" which took about 8 minutes. The graph shows a sharp rise in water temperature for the improved stove indicating a high energy release. It also shows a steady decline in water temperature, as compared to that of the "Lo-Trau". Ash on the ashport of the "Lo trau" must be removed to agitate the fuel bed and maintain the flame.

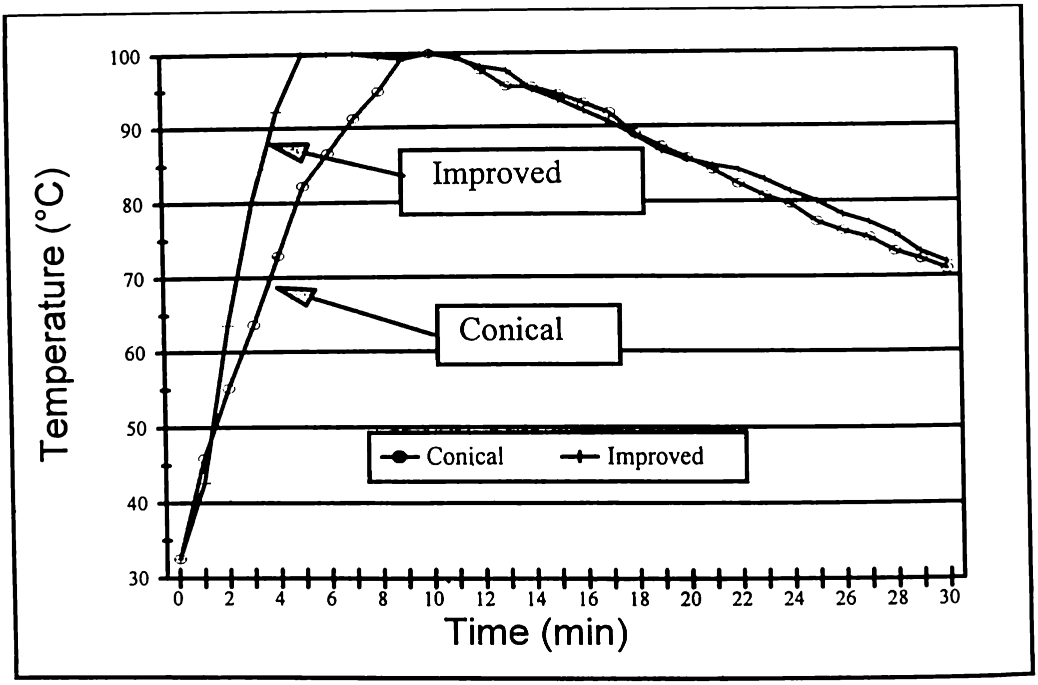

Figure 6. Boiling test of conical grate cookstove and improved rice hull-biomass cookstove.

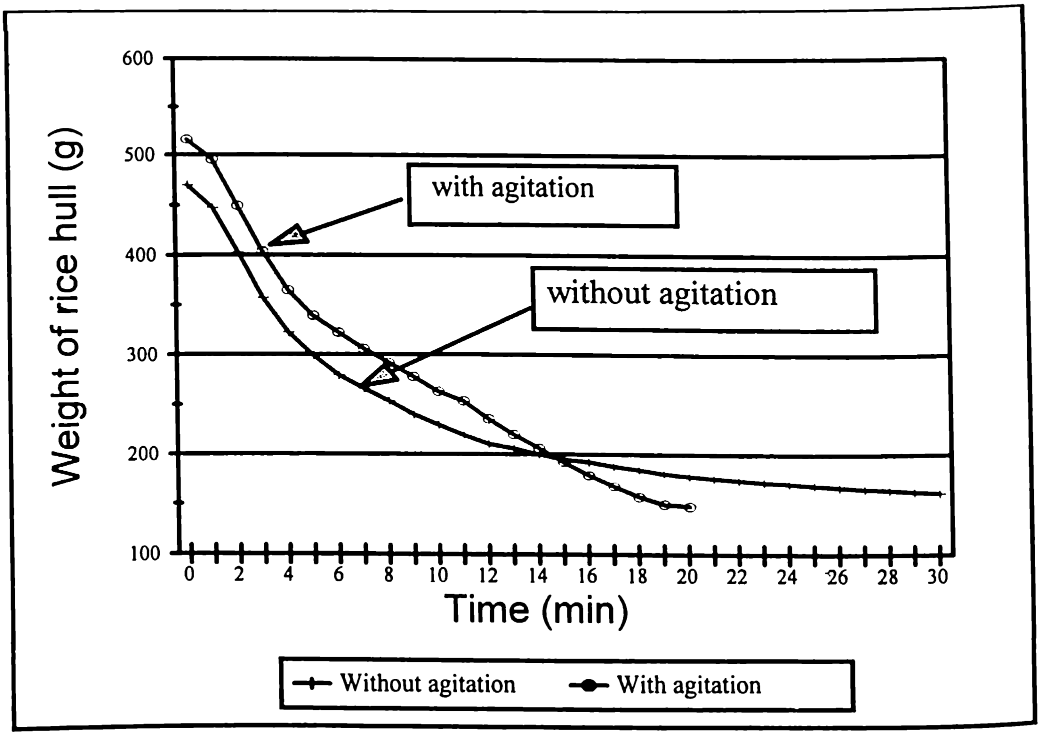

Figure 7. Rice hull consumption of improved rice hull-biomass cookstove

4.3 Rice hull consumption

Rice hull consumption can be inferred from the graph (Figure 7). For a normal operating period of 20 minutes, decrease in weight is only 350 g. This can be extended up to 30 minutes without manipulating the ashport, but with a decreasing temperature as shown in Figure 7. The improved rice hull/biomass stove requires from 1.0 kg to 1.50 kg rice hull for a one-hour cooking session. Based on the boiling tests and rice hull consumption trials, heat utilization efficiency ranged from 12-24% using rice hull at 4% MC_{wb} and 13 MJ/kg heating value. Power-time relationship is shown in Figure 8.

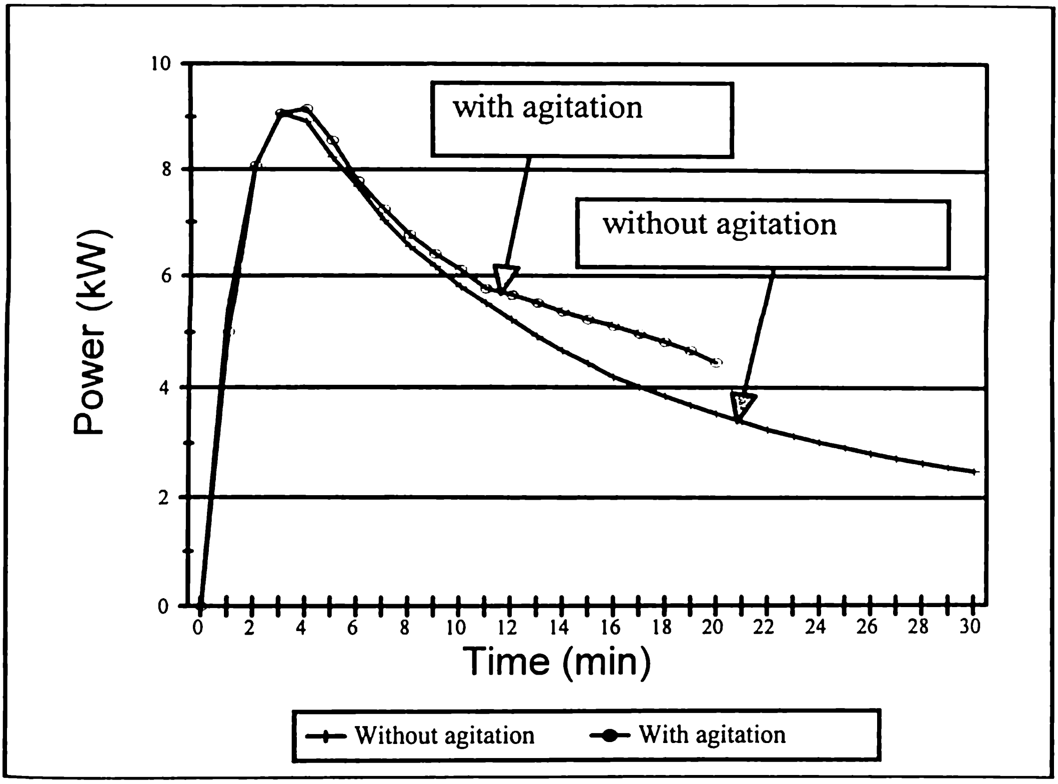

Figure 8. Power-time relationship of improved rice hull-biomass cookstove (using rice hull only).

4.4 Stove fabrication

Fabrication of stove is possible using only a limited number of workshop tools such as tin-snip, sheet metal cutter, punch and/or hand drill, arc welder and/or acetylene gear. These tools are common accessories in a small-scale welding shop. Scrap materials such as used sheet metal, tin cans, metal rods, can be recycled to assemble the cookstove. The design was made available to interested parties using only a written guide and accompanying drawings.

4.5 Feedback from users of rice hull/biomass stove.

Prototypes were left with several cooperators in selected sites to assess the acceptability of the rice hull-biomass cookstove. Candid comments were received from users. In Mindoro, the rice hull-biomass cookstove has been labelled "Ipa-gasul", qualifying the flame as approaching that of LPG. In Tagbilaran City, Fr. Leo Mateo, Diocesan Superintendent, commends the stove, saying more people should use it. LPG users cites up to 50% savings in cooking gas using the rice hull cookstove. Some households continued to use kerosene due to higher cost of transporting rice hull than when buying kerosene.

5.0 CONCLUSION AND RECOMMENDATION

A rice hull-biomass cooking stove which combined the center tube-conical grate-nozzle stove principles was developed (Fig. 9). It successfully uses rice hull as fuel. Other particulate biomass fuels, such as sawdust, may be used in combination with rice hull, but must use rice hull as base biofuel. Sawdust as fuel may be mixed with rice hull in a one to one ratio by volume. Cracked coconut shells and cut coconut husks can be used as fuel by loading after a layer of rice

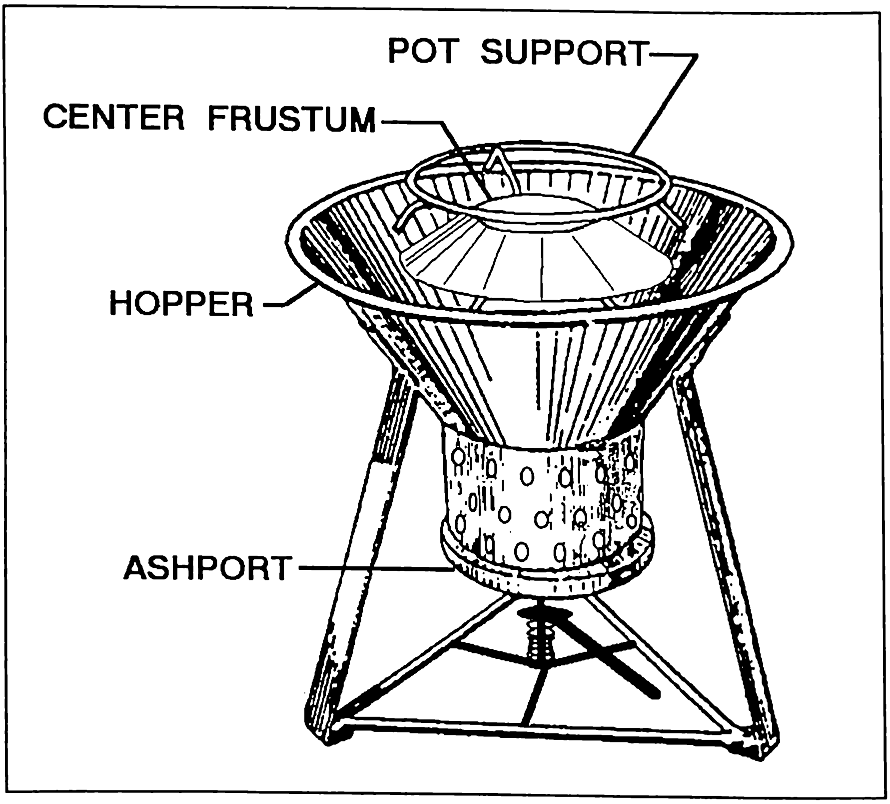

Figure 9. Schematic diagram of improved rice hull-biomass cookstove

hull. Longer periods of up 25 min sustained flame were observed using rice hull-sawdust, rice hull-coconut shell, rice hull-coconut husk biofuels combinations, than when using rice hull alone. The versatility of the rice hull-biomass cookstove to use biofuels has direct bearing to national efforts to protect the environment, particularly reducing and/or eliminating the cutting of trees.

The improved stove has convenient cooking features in terms of the following: easy firing, low smoke level, low user attendance, low fabrication cost, and simple design. Use of scrap materials such as used sheet metal, tin cans and drums to fabricate the stove, encourages enhanced recycling activity. Entrepreneurs can also take advantage of stove-making as an opportunity to expand their business concerns.

With a high heat utilization efficiency of up to 20% using rice hull, a 25-kg bag of rice hull may be used for 21 cooking sessions or up to 7 days, at 3 sessions daily. Based on estimate, a family using rice hull as fuel for one year can possibly save the cutting of one hectare of forest or fuelwood stand. This is beneficial to both the environment and to our forest reserves.

Future work should emphasize increasing further, heat utilization efficiency. This might be possible by optimizing the size of the combustion zone, and the amount of open area acting as air vents. Scale-up prototypes have been fabricated for stove sizes with rice hull consumption of more than 3 kg/hr, this should fit dryer applications. Sizes that will function as an incinerator with rice hull as base material should continue to be explored. Rendering of the stove in clay material might be possible, however, feasibility of the manufacturing process should be investigated.

ACKNOWLEDGEMENT

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APPENDIX

Saving a one-hectare forest by planting a 2-hectare ricefarm

Assuming rice hull @ 3 kg per day per 6-person household using rice hull cookstove is sufficient for one day cooking

3 kg x 365 days per year = 1.095 ton rice hull, this is equivalent to:

$$\frac{1.095 \text{ ton rice hull}}{0.2 \text{ ton rice hull per ton paddy}} = 5.475 \text{ ton paddy.}$$

Also, 1 cropping in a year at 2.5-ton yield/ha, will require a planting area of

$$\frac{5.475 \text{ ton}}{2.5 \text{ ton/ha}} = 2.19 \text{ ha}$$

Therefore, a one-ha farm will have sufficient rice hull provided 2 croppings per year is possible or doubling the yield per hectare from 2.5 tons/ha to 5 tons/ha.

Using wood, the same household will use more than 6 kg wood per day

6 kg x 365 days/yr = 2.190 ton fuelwood
or a fuelwood volume of

$$\frac{2.190 \text{ tons}}{0.7 \text{ ton/m}^3} = 3.12 \text{ m}^3$$

Since a growing stock of a fuelwood stand yields only 1.95 m^3/ha per year a deficit of

$3.12 \text{ m}^3 - 1.95 \text{ m}^3 = 1.17 \text{ m}^3$ exist;

which is from a fuelwood forest area of about
0.6 ha (1.17/1.95). A deficit is already consumed
which explains part of the deforestation.

At 2.5 ton/ha paddy yield, available rice hull is 0.5 ton which is equivalent to 0.36 ton firewood or 0.51 m^3 fuelwood which is approximately 0.25 ha of fuelwood forest. To be able to compensate for the 0.6 ha fuelwood forest deficit two croppings at 2.9 ton /ha is therefore needed.