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DESIGN AND PERFORMANCE EVALUATION OF A BATCH-TYPE RICE HULL GASIFIER STOVE[1]

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ABSTRACT

A batch-type rice hull gasifier stove was designed and its performance as a potential alternative fuel saving device for cooking was evaluated.

The stove is a single-burner with a double-core, down-draft type reactor. Gas is generated in the system by using a suction blower driven by a 90-watt electric motor.

Performance evaluation showed that the stove has a start-up time of 4 to 9 min and a total operating period of 0.98 to 1.25 hour per batch with corresponding rice hull consumption of 1.96 to 2.72 kg. About 1.2 to 4.0 liters of water can be boiled in the stove within 10 to 34 min while 0.7 to 1.0 kg rice can be cooked within 16 to 22 min.

Analysis showed that the stove has a gasification rate of 95 to 143 kg/m^2-hr, a fire zone rate of 0.80 to 1.02 cm/min, and an average burning and thermal efficiencies of 21 and 10%, respectively.

The stove entailed an operation cost of P0.94/hr and a payback period based on electric, charcoal, and LPG stoves of 0.42, 1.30, and 3.35 years, respectively.

Introduction

Most families in the rural areas are now facing the problems of using conventional energy sources of fuel for cooking owing to the continuing increase in the prices of kerosene, liquified petroleum gas (LPG) and electricity. Firewood and charcoal are the best alternatives, but their decreasing availability (GATE/GTZ, 1984) is a problem.

Agricultural waste like rice hull is a biomass fuel that is a potential alternative source of energy which could replace fossil fuel, wood and charcoal. But using wood and charcoal would gradually deplete our forest (Belonio, *et al.*, 1989).

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Rice hull is abundant in most localities and can be found at the back of most rice mills and/or along the sides of highways where it is being dumped and burned to avoid accumulation of bigger volumes. The improper disposal and burning of this waste product resulted in a waste of millions of calories.

Several attempts have already been done to develop low-cost devices utilizing rice hull as fuel for heating, but none has gained wider acceptance due to the problem of operation (Beagle, 1978; GATE/GTZ, 1984; and Stickney, *et al.*, 1987). Gasifying rice hull for domestic use has a potential application (Stickney, *et al.*, 1987). Through gasification, one can operate a stove conveniently similar to an LPG stove while utilizing electrical energy at very minimal cost.

This study was conducted to design and evaluate the performance of a batch-type rice hull gasifier stove.

DESIGN CRITERIA AND BASIC DESCRIPTION OF THE DESIGN

The following criteria were considered in the design of the batch-type rice hull gasifier stove:

1. Continuity of operation – capacity to operate continuously for one hour with sufficient energy to provide heat for cooking.
2. Convenience of operation – non-intensive attendance during use.
3. Safety in operation – freedom from possible leakage of undersirable gases.
4. Portability – ease of transfer from one place to another, if desired.
5. Economy – low initial and maintenance cost.

Based on these criteria, a double-core, down-draft type reactor was designed in such a way that it is directly coupled into the burner to simplify operation. A chimney was also provided to safely discharge undesirable gases.

The Batch-Type Rice Hull Gasifier Stove

The batch-type rice hull gasifier stove as shown in Figure 1 consists of the following major components: 1) reactor, 2) suction blower, 3) burner, 4) tar collector, and 5) T-chimney. The design specifications of these components such as the diameter and length of the reactor, and airflow rate and static pressure requirement of the suction blower were computed using the equations presented in Appendix 1:

Reactor. The reactor is a double-core cylinder made of a cold-roll black iron (B.I.) sheet gage No. 20. The inner and outer cores have a diameter of 15 and 20 cm, respectively, allowing 2.5 cm annular space for the passage of gas. Its length of 65 cm ensures continuous operation for one hour and its conical shape bottom with a clip-type door makes discharge of char easy. A screen covering is provided to protect the operator from touching the reactor. Directly beneath the inner core, a flat grate made of 3 mm diameter round bar spaced 6 mm apart is attached to hold

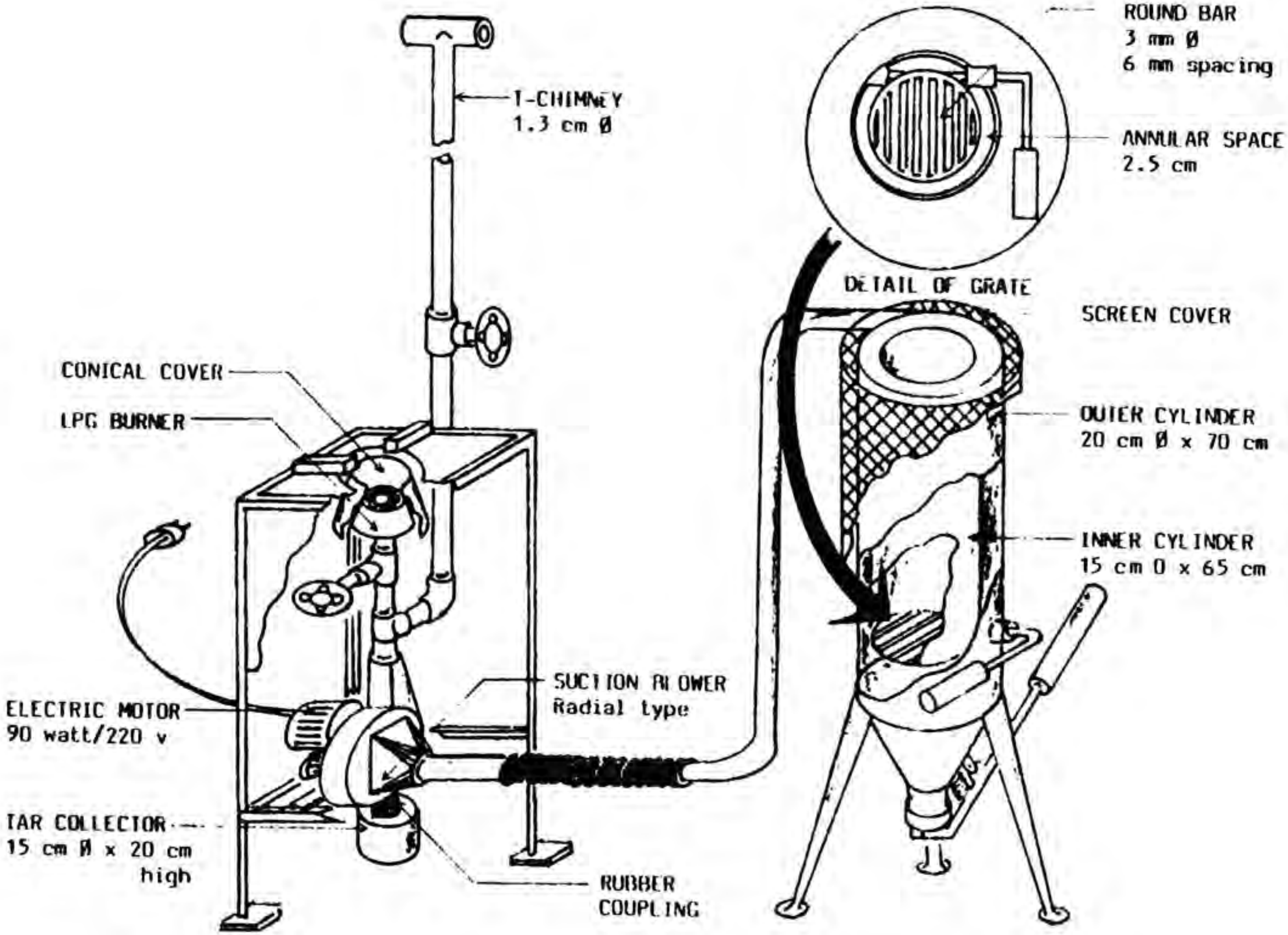


Figure 1. Technical drawing of the batch-type rice hull gasifier stove.

the fuel. This grate can be tilted to facilitate the removal of char. Three identical legs are welded to support the reactor.

Suction Blower. A backward-type high static pressure blower made out of B.I. sheet gage 18 sucks gas from the reactor. Its impeller has eight blades each with a diameter of 15 cm and a width of 5 cm. A 90-watt sewing machine electric motor drives the blower.

Burner. A standard LPG-type (7.5 cm D) burner stove with a 1.3 cm diameter gate valve regulates the flow of gas. Directly above the burner, a conical cover provides proper combustion and minimizes heat loss.

Tar Collector. Condensing tars on the piping of the stove during operation are collected in a tar container beneath the blower. This container at the lowest most portion of the stove collects tars from the pipings. It has a design capacity of 3.5 liters sufficient to collect tars for a one-week operation. To minimize the leakage of gas, a thermal resistant rubber tubing is used as coupler.

T-Chimney. A 1.3 cm diameter B.I. pipe is used as chimney. It is connected to the pipe installed between the blower and the burner to easily divert and discharge undesirable gases during operation. A gate valve controls the flow of gas.

METHODOLOGY OF PERFORMANCE EVALUATION

Materials and Equipment

Rice hull with moisture content of about 13% which was obtained from a rubber roll type rice mill was used as fuel in testing the performance of the stove.

The weight of fuel used and the corresponding char produced during gasification were measured with a 10-kg capacity spring-type balance. At each test, the time required to finish a run was recorded with a stop watch.

In boiling water and in cooking rice, a standard-sized aluminum casserole (8 cm D) was used as container. Initial and final temperatures of water were taken using a dial-type bimetallic thermometer (150 C max 2 C acc). Ambient air temperature and relative humidity were taken with a sling-type pyschrometer (43 C max 1 C acc).

The energy content of rice hull and char after the performance evaluation was determined on a 1341 Plain Jacket Oxygen Bomb Calorimeter.

Performance Evaluation Procedure

The performance of the stove was evaluated in actual condition at Brgy. Balicua, Tubunga, Iloilo during the month of December 1987. The unit was installed in an open shade to allow free passage of air.

Operation was started by initially loading two handfuls of rice hull at the reactor occupying approximately 5 cm depth serving as primer. The fuel was ignited by dropping burning pieces of paper and then switching on the blower. After proper ignition was attained, i.e. approximately 3/4 of the total area occupied by rice hull was burning, the reactor was fully filled with rice hull. Successive loadings of fuel were made at different intervals until the reactor was filled with the accumulated char.

The time required to generate combustible gas at the start and at 10-min lag period between operations was taken during the tests to determine the start-up time of the stove. The amount of rice hull fuel consumed in each run was recorded to determine the gasification rate of the stove. The depths of char between successive loadings were also measured to monitor the rate of the fire zone in moving along the reactor. The corresponding amount of char produced was also measured after each run.

Boiling time test was conducted by subjecting 1.2, 2.0, and 4.0 liters of water. The corresponding amount of water evaporated during this test was taken to evaluate the thermal efficiency of the stove. Cooking time test, on the other hand, was carried out by cooking 0.7, 0.9, and 1.0 kg rice (IR-64) with different volumes (1.12 – 1.50 liters) of water used. Ambient air temperature and relative humidity were also recorded in each run.

Analysis of the energy content of rice hull fuel used and the char produced during the study was also conducted to determine the burning efficiency of the stove.

Results and Discussion

Operating Performance

Series of test runs were conducted in evaluating the performance of the stove. The ambient air temperature and the relative humidity during the tests ranged from 27 to 29 C, and 70 to 90%, respectively.

As illustrated in Figure 2, flammable gases are generated in the reactor through the suction created by the blower wherein the air upon contact with the burning rice hull at the fire zone is converted into gases, primarily carbon monoxide (CO). These gases leave the reactor through the annular space between the inner and outer cylinders. As clearly shown in the figure, the outlet is positioned tangentially to the reactor to allow uniform heating as well as separation of fly ashes. Primary air, on the other hand, is provided in the burner for proper combustion through a conical cover directly installed above it. Tar is separated from the gas by condensation while passing through the pipings.

Results showed that immeditely after igniting rice hull in the reactor, about 4 to 5 min is required before combustible gas can be generated(Figure3). Note that the undesirable gases produced during the start-up of the stove are diverted outside the shed by closing the valve at the burner while opening the valve at the chimney. Switching off the stove for 10 minutes between operations requires a longer time of about 4 to 9 minutes before gas can be re-generated.

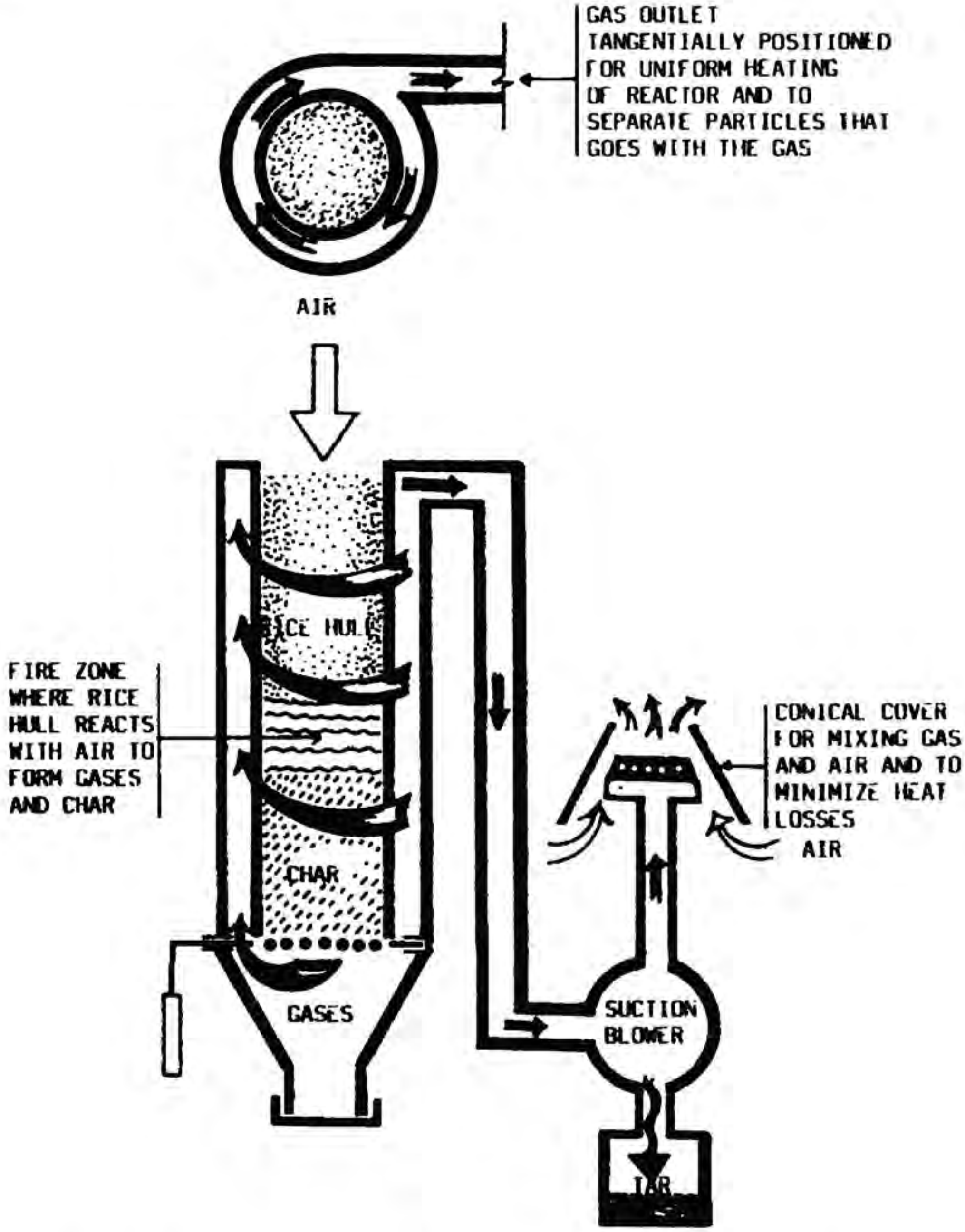
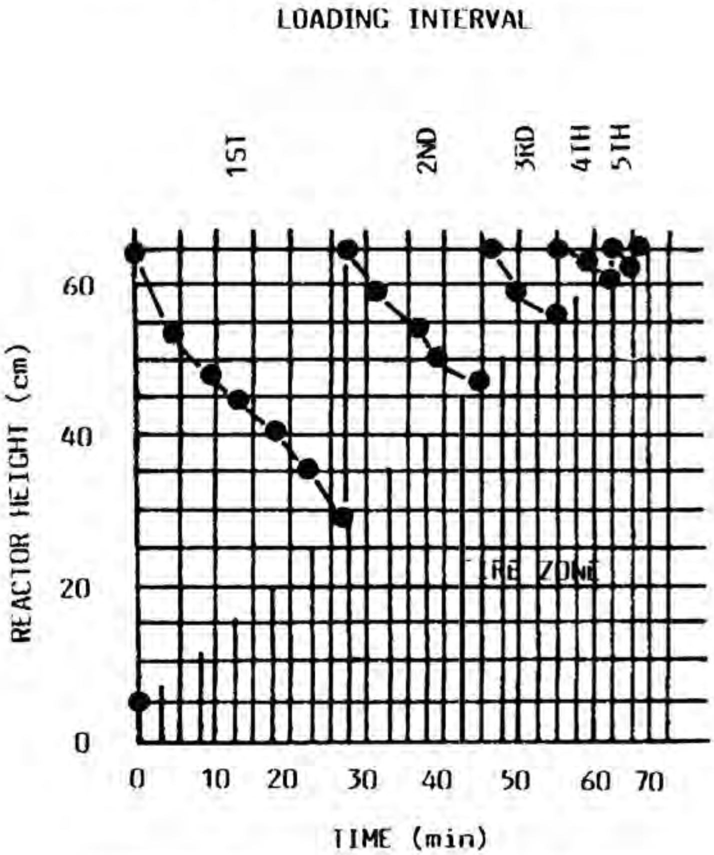


Figure 2. Illustrative example of the gas generation of the rice hull gasifier stove.

It can be further observed in Figure 3 that in continuous operation of the stove, successive loadings of rice hull is necessary before completing a batch. The need to successively load fuel in the reactor basically can be attributed to the decrease in the volume of rice hull which is converted into char upon burning. In each batch, about 5 to 6 loadings are required. Loading time interval, as shown in the same figure, decreases with time.



	START-UP TIME (min)
At the start of operation	4 – 5
At 10-min Lag period	4 – 9

Figure 3. Operating performances of the rice hull gasifier stove.

Performance test results for the three separate runs showed that the stove can be continuously operated within 0.98 to 1.25 hr. (Table 1). The corresponding weight of rice hull consumed and char produced ranged from 1.96 to 2.72 kg and 0.53 to 1.04 kg, respectively. The computed gasification rate which is the ratio of the rate of burning rice hull per unit area of the reactor of 0.0047 square meter range from 95 to 143 kg/m*2-hr. This result is also within the range of the standard gasification rate of rice hull gasifiers which is 100-210 kg/m*2-hr (Kaupp, 1984). The fire zone rate which is the time required for the fire zone to reach the top most portion of the reactor, on the other hand, ranged from 0.8 to 1.02 cm/min.

Table 1. Operating performance of the batch-type rice hull gasifier stove on three different runs

Run	*Operating Period[1] (hr)*	*Weight of Fuel Consumed (kg)*	*Weight of Char Produced (kg)*	*Gasification Rate[2] (kg/m^2-h)*	*Fire Zone Rate[3] (cm/min)*
1	0.98	1.96	0.53	114	1.02
2	1.08	2.72	1.04	143	0.93
3	1.25	2.09	0.55	95	0.80

[1] Measured from the time after a combustible gas is produced until the the reactor is completely filled with char.

$$^2\ \frac{\text{weight of fuel used}}{\text{area of the reactor x time of operation}}$$

$$^3\ \frac{\text{length of reactor}}{\text{time of operation}}$$

Boiling and Cooking Time

Results of boiling and cooking time tests as indicated in Table 2 revealed that the stove can boil 1.2 to 4.0 liters of water initially from 28 C within 10 to 34 minutes and cook 0.7 to 1.0 kg rice with 1.12 to 1.50 liters of water within 16 to 22 minutes. It was observed during the test that the more water is boiled and the more rice is cooked, the longer is the time required in operating the stove. However, for typical rural families, results of tests on boiling and cooking time indicated that the unit can sufficiently provide the needed heat requirement per operation.

Table 2. Summary of the results of the boiling and cooking time tests of water and rice in the stove*

Volume of Water and/or Weight of Rice	*Boiling/Cooking Time (min)*
1.2 to 4.0 liters of water	10-34
0.7 to 1.0 kg of rice (IR-64) with 1.12 to 1.50 liters of water	16-22

*Averages of nine (9) runs conducted in Barangay Balicua, Tubungan, Iloilo during the month of December 1987.

Burning and Thermal Efficiency

In determining the burning efficiency of the stove, the percentage heat liberated method as mathematically expressed below was used:

$$BE = \frac{HErh - HEc}{HErh} \times 100$$

where:

BE – burning efficiency, %
HErh – heat energy content of rice hull, kcal/g
HEc – heat energy content of char, kcal/g

Based on the heat energy content of rice hull and the char obtained in the bomb calorimeter tests which averaged 3.620 kcal/g for rice hull and 2.876 kcal/g for char, the burning efficiency for the rice hull gasifier stove was 21%. The process of gasifying fuel which only converts rice hull into char rather than into ash gave a relatively lower burning efficiency for the stove.

The thermal efficiency of the stove was computed using the equation:

$$TE = \frac{W\ Cp\ (T2-T1) + We\ Hfg}{Wf\ HVF} \times 100$$

where:

TE – thermal efficiency, %
W – weight of water, kg
Cp – specific heat of water at constant pressure, kcal/kg-C
T2 – final temperature of water, C
T1 – initial temperature of water, C
We – weight of water evaporated, kg
Hfg – latent heat of vaporization, kcal/kg
Wf – weight of fuel consumed, kg
HVF – heating value of fuel, kcal/kg

With the average amount of rice hull fuel consumed of 2.26 kg and a corresponding amount of heat utilized of 818.12 kcal (combining both the sensible and latent heat during heting and evaporation of water) gave a thermal efficiency for the stove of 10%. Similarly, the process of gasifying rice hull as well as the use of uninsulated metal sheet which radiated some heat during the operation gave a relatively lower thermal efficiency for the stove. However, the result obtained can still be considered valid since it is in the range of efficiencies of various charcoal (2.5 – 12%) and open firewood (3 – 11%) stoves (Appovecho Institute, 1984).

Table 3. Cost analysis of operating the stove

Investment Cost (IC)		P1,500.00
Fixed Cost (P/yr)		
Depreciation[a]	675.00	
Interest on Investment[b]	75.00	
Repair and Maintenance[c]	45.00	
Total	795.00	
Variable Cost (P/yr)		
Fuel[d]	43.20	
Electricity[e]	172.80	
Total	216.00	
Total Operating Time (hr/yr)[f]	1080	
Operating Cost (P/hr)	0.94	
Payback Period (Yr)		
Electric Stove[g]	0.42	
Wood Charcoal Stove[h]	1.30	
LPG Stove[j]	3.35	

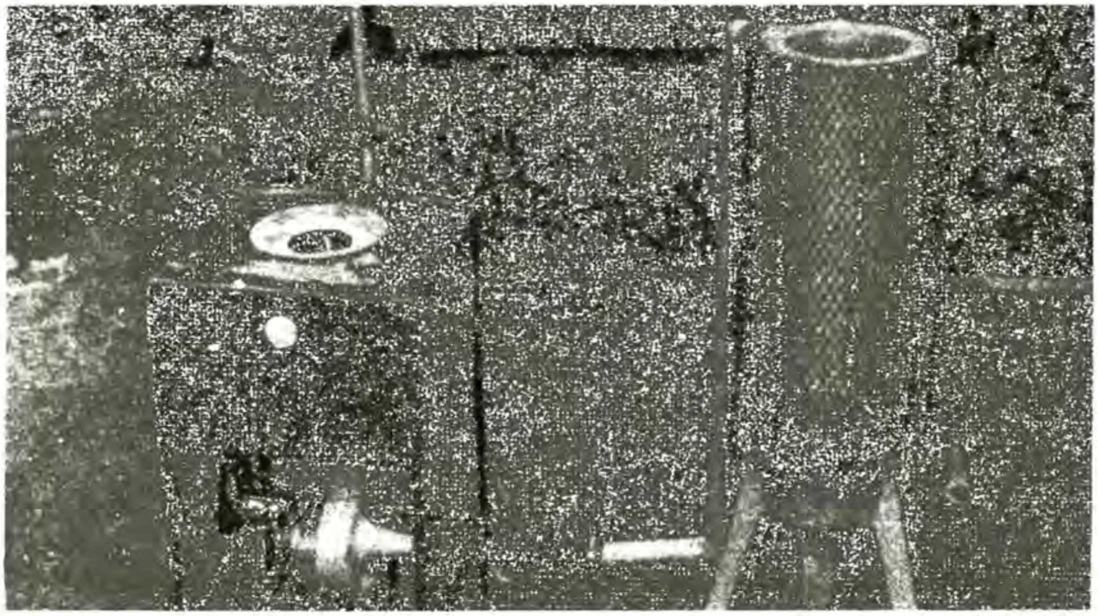
[a]Straight line method at 10% salvage value and 2 yr life span (LS)
[b]5% of IC
[c]3% of IC
[d]P 0.25/sack (10 kg/sack), 1 hour operation at 1.8 kg/hr
[e]90 watt-hour at P 1.80/kw-hr
[f]3 hours/day operation.
[g]P 720.00/unit, 2.24 kw, 220 v, 40% eff., and 1 yr LS
[h]P 25.00/unit, 2 kg/hr at P 4.00/kg, 6% eff., and 0.5 yr LS
[j]P 775.00/unit (including tank), 1.3 months/tank at P 91.60/tank, 40% eff., and 2 yr LS.

Economic Considerations

The ability of the rice hull gasifier stove to produce flammable gas out of rice hull with the minimum use of electricity (P0.16/hr solely for driving the blower) is an economic advantage.

With an initial investment of ₱1,500 for the stove and a combined cost of ₱0.20/hr, for hauling fuel and electricity the unit entailed an operating cost of ₱0.94/hr only.

The stove can be paid after 0.42, 1.3, and 3.35 years of operation compared to electric, wood charcoal, and liquified petroleum (LPG) gas stoves, respectively.



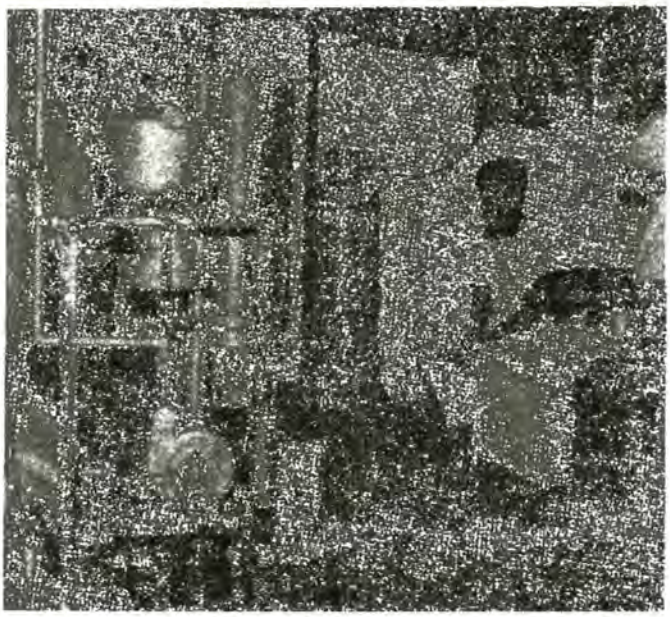


Figure 4. Photographs showing the rice hull gasifier stove: (a) Pictorial view, and (b) during operation.

Concluding Remarks

The stove is a potential alternative fuel-saving device which produces combustible gas out of rice hull. It can be conveniently operated continuously for an hour with sufficient amount of heat for cooking.

The stove is more economical to use compared with electricity and wood charcoal stoves.

Further modifications in the design to improve the efficiency and to reduce the initial cost of the stove are recommended for future study.

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Appendix 1. Equation used in the design of the batch-type rice hull gasifier stove.

A. NOMENCLATURE

Symbols	*Notations*
AFR	airflow rate requirement, m3/min
D	diameter of the reactor, m
Dg	gas density, kg/m^3
Eb	burner efficiency, %
Eg	gasifier efficiency, %
FZR	fire zone rate, m/min
GFR	gas flow rate, m3/min
HVG	heating value of gas, kcal/m^3

Qd	energy demand, kcal/hr
L	length of the reactor, m
sp	static pressure requirement of char, cm of water/m depth of char
SA	stoichiometric air requirement, kg of air/kg of fuel
SGR	specific gasification rate, kg/m^2-hr
SP	total static pressure requirement of the blower, cm of water
T	operating time, min

B. EQUATIONS

a) Gas Flow Rate

$$GFR = AFR = \frac{Qd}{Eb \times HVG}$$

b) Weight of Rice Hull

$$WRH = \frac{GFR \times DG}{0.32 \times SA \times EG}$$

c) Diameter of the Reactor

$$D = \left[\frac{1.27 \times WRH}{SGR} \right]$$

d) Length of the Reactor

$$L = FZR \times T$$

e) Static Pressure Requirement

$$SP = sp \times L$$