EVALUATION OF THE DIFFERENT RICE HULL GASIFIER STOVES DEVELOPED AT CPU APPROTECH CENTER

By Aries Roda D. Romallosa

ABSTRACT

Four gasifier stoves, all developed at the Appropriate Technology Center (APPROTECH Center) of CPU, were evaluated in this study in terms of fuel consumption rate, percentage char produced, fire zone rate, thermal efficiency, and electric energy consumption rate. These include: Gasifier A or the cylindrical-type single-burner, top-lit updraft (T-LUD); Gasifier B or the cylindrical-type double-burner, T-LUD (for household use); Gasifier C or the conical-type double-burner T-LUD (for household use), and Gasifier D or the conical-type double-burner T-LUD (for industrial use). Evaluation was conducted at the APPROTECH Center on April 23 to May 29, 2007. Results of the study revealed that Gasifier A significantly ($p<0.01$) had the highest percentage production of char and thermal efficiency while Gasifier D significantly ($p<0.01$) produced the highest fuel consumption rate. In general, however, all the three double-burner stoves (Gasifiers B, C, and D) significantly ($p<0.01$) had higher fire zone rate and consumption of electric energy compared to Gasifier A since these three stoves have two burners and use an electric blower as air moving device, thus consuming more fuel and electric energy. The gas emitted by the gasifier stoves were estimated to contain from 20 to 24% carbon monoxide, 13 to 23% hydrogen gas, 8 to 15% carbon dioxide, 38 to 42% nitrogen, 0 to 2% methane and 7 to 9% water or moisture. Among the gasifiers evaluated, only Gasifier A has the economic advantage over the LPG stove making it ideal when used at the household level. Due to their high investment cost and low economic return, the double-burner stoves (Gasifiers B, C, and D) can still be used for bigger and longer cooking operations.

INTRODUCTION

According to reports, the total rice hull of the country was estimated to be 2.26 million tons in 1996. Iloilo alone has 2 National Food Authority (NFA) units and 403 private units of rice mills producing an approximate volume of 45,000 tons of rice hulls (Vergara, 1998). This tremendous agricultural waste often causes disposal problems especially on the part of rice millers. A study on biomass as an energy source revealed that the use of agricultural residues like rice hull, which are currently disposed by dumping or burning can provide further energy service in the Philippines (from http://www.crest.org/discussiongroups/resources/stoves/Countries/Biomass%20phil%20 presentation.pdf). This is because the energy value of Philippine rice hull is 11.7 $\pm$ 0.9 MJ/kg at 14% moisture and 19.4% ash. In comparison, most dry woods contain from 18 to 20 MJ/kg, and coal contains 25 to 30 MJ/kg. The higher the ash content of rice hull, the lower the calorific value. Rice hull is also considered as a flame retarding material. As a fuel, it is difficult to burn if applied in a heap. It will only smolder, but not burn (Gerpacio & Castillo, 1979). If enough oxygen, however, is provided, it will ignite (Goyal & Maheshwari, 1978). It has a heating value of about 3600 kcal/kg (Jain, 2006). In order to completely burn it, 4.5 kg of air is needed per kg of rice hull. Burning it using 30 to 40% or an equivalence ratio of 0.3 to 0.4 only of the air needed for combustion will gasify rice hulls producing a flammable bluish flame (Belonio, 2005).

In the early 2000, the Appropriate Technology Center (APPROTECH Center) which is under the College of Agriculture of this university, started the development of low cost technologies that utilize rice hull as fuel with the aim of helping solve the problem on its disposal. Some of these technologies developed employ the gasification process, in which fuel is converted into producer gas by means of partial oxidation at an elevated temperature. The resulting producer gas from this technology known as gasifier contains carbon monoxide, hydrogen, methane and other hydrocarbons which are combustible.

The APPROTECH Center started with the development of the CPU single-burner batch-type gasifier stove which aimed to provide individual households a technology for domestic cooking that utilizes rice hull as fuel. It was followed by the development of two similar designs of a proto-type inverted downdraft/top lit updraft (IDD/T-

LUD) gasifier rice hull gas stove. Then a cross-flow type rice husk gasifier stove was designed, which was patterned after the Asian Institute of Technology (AIT) wood gasifier stove. The stove was designed in an attempt to gasify rice hull in a continuous mode in order for the operation to be done continuously, as desired also by the user. The APPROTECH Center also developed a gasifier that is fueled by wood. This was the CPU IDD/T-LUD wood gasifier stove which is similar in design to the previously developed IDD/T-LUD rice hull gas stove (Belonio, 2005). These different designs of gasifier stoves have led to the development of the gasifiers that were evaluated in the study.

Objectives of the Study

The general objective of the study was to evaluate the different rice hull gasifier stoves developed at the APPROTECH Center of CPU. Specifically, it aimed:

1. to evaluate the performance of each gasifier stove in terms of fuel consumption rate, percentage char produced, fire zone rate, thermal efficiency, and electric energy consumption rate;
2. to determine if the fuel consumption rate, percentage char produced, fire zone rate, thermal efficiency, and electric energy consumption rate of the different gasifiers developed are significantly different from each other;
3. to determine the potential gas composition of the producer gas emitted from the gasifier such as carbon monoxide (CO), hydrogen gas (H_2), carbon dioxide (CO_2), nitrogen (N_2), water (H_2O), and methane (CH_4) as a function of gas output and reactor temperature; and,
4. to analyze the cost and returns of operating each technology.

Time and Place of the Study

This study covered the evaluation of the performance operation of the four gasifier technologies developed at CPU APPROTECH Center. It also included the determination of the potential gas composition of the producer gas emitted by the burners of the gasifiers developed. Evaluation of the technologies was conducted at the APPROTECH Center of the College of Agriculture of this University last March 27 to April 31, 2007.

METHODOLOGY

Research Design and Sampling

This study evaluated in three test runs the operating performance of the gasifier technologies developed at CPU APPROTECH Center that makes use of rice hull as fuel. Further, the gases emitted from these technologies were also determined using the STANJAN program developed at the Department of Mechanical Engineering of Stanford University.

The rice hull gasifiers developed at the APPROTECH Center for evaluation were chosen using the non-probability type of sampling. Rice hulls that were used for this study were obtained from one rice mill only to assure uniformity during testing.

Description of the Rice Hull Gasifier Stoves

Four rice hull gasifier stoves developed at the APPROTECH were evaluated in this study. These technologies, which are all classified as top-lit updraft (T-LUD) with batch-type mode of feeding, are the following: a. cylindrical-type single-burner gasifier stove, Gasifier A (Figure 1); b. cylindrical-type double-burner gasifier stove, Gasifier B (Figure 2); c. conical-type double-burner gasifier stove, Gasifier C (Figure 3); and d. conical-type double-burner gasifier stove, Gasifier D (Figure 4). As shown in the figures, Gasifiers A, B, and C were classified for household use because of their smaller burner and reactor, making them more suitable for smaller and shorter household cooking. On the other hand, Gasifier D was classified for industrial use due to its bigger burner and reactor size which are suited for bigger and longer cooking operations normally done in the industry or in commercial operations.

Evaluation

Performance evaluation. The procedures in evaluating the four gasifier stoves were similar since they were all top-lit updraft gasifiers with a batch-type mode of loading. Dry rice hulls were measured and loaded into the reactor until it was full. After which, the fuel was ignited using burning pieces of paper while the air moving device was switched on. Control of air supply coming from the fan or blower was responsible in delivering the needed amount of primary air for gasification to produce combustible gas for cooking. When the fire spread over the rice hull in the reactor, its cover was put in place to ensure that no heat escapes upward. In the case of the single-burner stove, the burner itself was placed on top of the reactor instead of the cover. Aluminum cooking pots having specific volume of water were then placed on the pot holders for the water boiling test in order to determine the thermal efficiency of the stoves. The final weight of the water in the aluminum cooking pot was measured after the operation was done. The time required in igniting the rice hull fuel in the reactor and the time the gasifier stove started to generate producer gas were also measured during each run. Temperature of the water during the boiling test procedure and the total operating time of the stove were also determined. After all the necessary data were gathered, the following parameters were analyzed: fuel consumption rate, percentage char produced, fire zone rate, thermal efficiency, electric energy consumption rate, operating cost, net operating income, return on investment, benefit-cost ratio, and payback period.

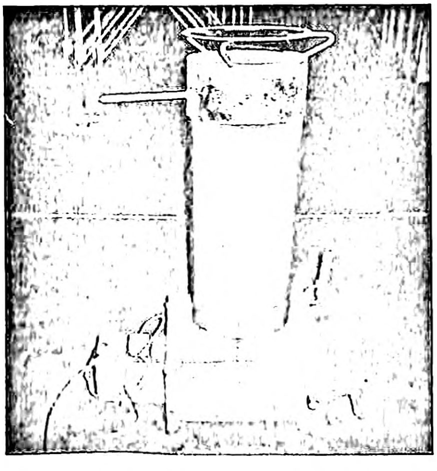

Figure 1. Gasifier A or Cylindrical-Type Single-Burner T-LUD Batch-Type Gasifier Stove (for Household Use)

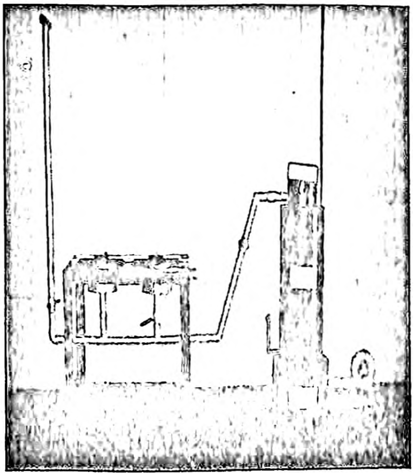

Figure 2. Gasifier B or Cylindrical-Type Double-Burner T-LUD Batch-Type Gasifier Stove (for Household Use)

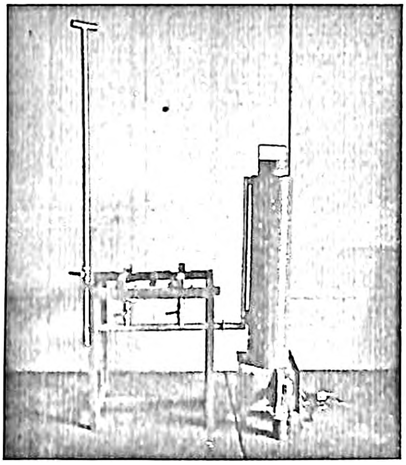

Figure 3. Gasifier C or Conical-Type Double-Burner T-LUD Batch-Type Gasifier Stove (for Household Use)

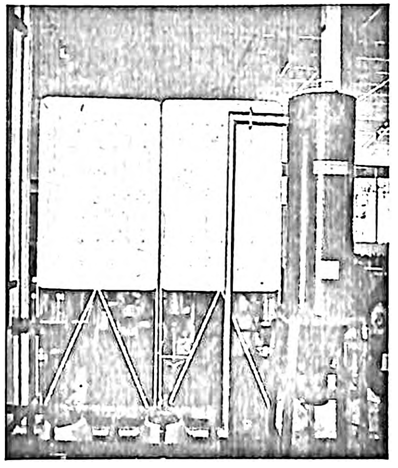

Figure 4. Gasifier D or Conical-Type Double-Burner T-LUD Batch-Type Gasifier Stove (for Industrial Use)

Potential gas composition of the producer gas. The potential gas composition of the producer gas emitted was approximated using a figure devised by Kaupp (1984) from the STANJAN program developed at the Stanford University Department of Mechanical Engineering. As recommended, the stoichiometric air or an equivalence ratio of 0.3 and a 10% moisture content for rice hulls were used. In using this figure, the average producer gas temperature of each gasifier stove expressed in degree Celsius is plotted against the composition of the producer gas expressed in mol fraction.

Instrumentation

The following were the instruments used during the evaluation of the stoves: AC clamp-on meter, 20-kg Fuji spring-scale balance, 25-cm diameter aluminum cooking pot, 100-ml and 1000-ml graduated cylinders, Kane-May Quintox combustion analyzer, Stanley steel tape, thermocouple wire thermometer, and timer.

RESULTS AND DISCUSSIONS

Specifications of the Rice Hull Gasifier Stoves Evaluated

Table 1 shows the design specifications of the four rice hull gasifier stoves evaluated in this study. Descriptions of the gasifier stoves are presented as follows: Gasifier A, cylindrical-type single-burner gasifier stove; Gasifier B, cylindrical-type double-burner gasifier stove; Gasifier C, conical-type double-burner gasifier stove; and Gasifier D, conical-type double-burner gasifier stove.

Operating Performance of the Rice Hull Gasifier Stoves

Fuel consumption rate. Data in Table 2 indicate that Gasifier A utilized the lowest average amount of fuel at 1.20 kg only, followed closely by the two-burner gasifier stoves designed for household use at 2.12 kg and 3.25 kg, respectively. Gasifier D which has the largest reactor capacity utilized an average of 14.70 kg. It took less than a minute (0.37, 0.45, and 0.73 min for Gasifiers B, D, and A, respectively), to ignite the rice hull fuel. All four gasifier stoves produced combustible gas at almost similar times, Gasifier C being the fastest at 2.13 min. The average total operating time of the gasifier stoves show that the technologies developed can use-up all the fuel loaded in the reactor in less than an hour. Statistical analysis of the average fuel consumption rate of the stoves revealed that Gasifier D had significantly ($p<0.01$) the highest fuel consumption rate at 17.07 kg/hr. Gasifiers B and C which are both double-burners but with different designs have almost similar ($p>0.01$) fuel consumption rate at 4.16 and 4.41 kg/hr, respectively. Gasifier A which is the only single-burner stove among the four also had significantly ($p<0.01$) the lowest fuel consumption rate at 1.61 kg/hr.

Table 1. Design Specifications of the Rice Hull Gasifier Stoves Evaluated.

Major Parts of the Gasifier Stoves	Specifications of Gasifier Stoves Evaluated			
	Gasifier A	Gasifier B	Gasifier C	Gasifier D
Reactor				
a. Inner dimension, cm	15 Ø x 60 H, stainless steel (SS) sheet # 18	20 Ø x 70 H, GI sheet # 18	20 Ø x 95 H, GI sheet # 18	40 Ø x 124 H GI sheet # 18
b. Outer dimension, cm	20 Ø x 60 H, GI sheet # 18	30 Ø x 70 H, GI sheet # 18	30 Ø x 95 H, GI sheet # 18	60 Ø x 124 H GI sheet # 18
Gas pipe, cm	none	4 Ø x 20 L, BI pipe S-20	4 Ø x 15 L, BI pipe, S-20	7 Ø x 60 L, BI pipe S-20
Gas regulator	none	2 ball valve (burner), 1 ball valve (exhaust)	2 ball valve (burner), 1 ball valve (exhaust)	2 ball valve (burner), 1 ball valve (exhaust)
Burner				
a. Type	Cylindrical	Cylindrical	Conical	Conical
b. Number	1	2	2	2
c. Dimension, cm	20 Ø x 13.5 H, SS sheet # 20	20 Ø x 12.6 H, GI sheet # 18	13 Ø x 6 H, GI sheet # 18	30 Ø x 10 H, GI sheet # 18
Chimney, cm	none	4 Ø x 145 H, BI pipe S-20	4 Ø x 145 H, BI pipe S-20	7 Ø x 230 H BI pipe S-20
Pot support, cm	3 – 1 Ø x 17 L, round bar	4 – 0.8 T x 21 L, square bar	4 – 0.3 T x 4.5 W x 18 L, angle bar	4 – 0.3 T x 4.5 W x 28 L, angle bar
Char lever, cm	1.2 Ø x 12 L, GI pipe S-20	1 Ø x 20 L, round bar	0.6 Ø x 20 L, round bar	1.2 Ø x 12 L GI pipe S-20
Char grate, cm	0.6 x 20 x 20, SS wire mesh	0.2 x 20 x 20, SS wire mesh	0.8 x 23 x 23, corrugated bar	0.6 x 60 Ø, SS wire mesh
Char chamber, cm	30 W x 32 L x 16 H, GI sheet # 18	38 Ø x 23 H, GI sheet # 18	40 W x 40 L x 20 H, GI sheet # 18	60 Ø x 28 H, GI sheet # 18 hopper
Control switch	220 V dimmer switch	220 V dimmer switch	220 V dimmer switch	220 V dimmer switch
Air moving device	fan	2 in. el. blower	2 in. el. blower	2 in. el. blower
a. wattage, watts	16	352	352	352

Table 2. Parameters Used and the Computed Average Fuel Consumption Rate of the Rice Hull Gasifier Stoves.

Gasifier	Ave. Weight of Fuel Used	Ave. Firing Time to Ignition	Ave. Firing Time to Gas Production	Ave. Total Operating Time	Ave. Fuel Consumption Rate
	kg	min	min	hr	kg/hr
A	1.20	0.73	2.23	0.75	1.61[c]
B	2.12	0.37	2.63	0.51	4.16[b]
C	3.25	1.22	2.13	0.74	4.41[b]
D	14.70	0.45	2.20	0.87	17.07[a]

cv = 4.64%

[abc] Any two means on the percentage char produced followed by the same letter superscript are not significantly different at the 1% level of probability.

Gasifier A cylindrical-type single-burner gasifier stove; Gasifier B cylindrical-type double-burner gasifier stove; Gasifier C conical-type double-burner gasifier stove; and Gasifier D conical-type double-burner gasifier stove

Percentage char produced. Results in Table 3 show that Gasifier A significantly ($p< 0.01$) produced the highest percentage of char at 28.05 % but not significantly higher than Gasifier B which produced 24.68%. On the other hand, Gasifier D yielded the lowest percentage of char at 21.91% but almost the same as those of Gasifiers B and C.

Fire zone rate. As shown in Table 4, the average fire zone rate of Gasifier D (1.44 m/hr) was analyzed to have significantly the highest value at the 1% level of probability followed by Gasifier B at 1.37 m/hr, and Gasifier C at 1.29 m/hr ($p>0.01$). Gasifier A, the only single-burner among the four, was analyzed to significantly ($p<0.01$) have the lowest rate for fire zone to move at 0.81 m/hr. It can be observed based on the results that the fire zone rate of a stove increases when the height or length of reactor also expands leading to a longer time in operation.

Table 3. Average Weight of Char Produced, Average Weight of Fuel Used, and Average Percentage Char Produced by the Rice Hull Gasifier Stoves.

Gasifier	Ave. Weight of Char Produced	Ave. Weight of Fuel Used	Ave. Percentage Char Produced
	kg	kg	%
A	0.34	1.20	28.05[a]
B	0.52	2.12	24.68[ab]
C	0.78	3.25	24.00[b]
D	3.22	14.70	21.91[b]

cv = 4.64%

[ab] Any two means on the percentage char produced followed by the same letter superscript are not significantly different at the 1% level of probability.

Gasifier A cylindrical-type single-burner gasifier stove; Gasifier B cylindrical-type double-burner gasifier stove; Gasifier C conical-type double-burner gasifier stove; and Gasifier D conical-type double-burner gasifier stove

Table 4. Average Height of the Reactor, Average Operating Time, and the Average Fire Zone Rate Produced by the Rice Hull Gasifier Stoves.

Gasifier	Ave. Height of the Reactor	Ave. Total Operating Time	Ave. Fire Zone Rate
	m	hr	m/hr
A	0.60	0.75	0.81[b]
B	0.70	0.51	1.37[a]
C	0.95	0.74	1.29[a]
D	1.24	0.87	1.44[a]

cv = 9.75%

[abc] Any two means on the percentage char produced followed by the same letter superscript are not significantly different at the 1% level of probability.

Thermal efficiency. The thermal efficiency of the four gasifier stoves ranged from 2.86% to 11.42%. Statistical analysis revealed that Gasifier A, having only a single burner and having the smallest reactor size among the four stoves had significantly ($p<0.01$) the highest thermal efficiency at 11.42 %, followed by Gasifiers B (4.74 %), C (3.82%), and D (2.86%), respectively, which were analyzed to have no significant difference from each other at the 1% level of probability (Table 5). It can be observed that as weight of the fuel increases more heat is also needed by the stove to gasify the fuel loaded, thereby decreasing its thermal efficiency.

Electric energy consumption rate. Data in Table 6 show that Gasifiers C, B, and D consumed relatively more electric energy during each operation at 17.16, 15.84, and 14.52 kW-hr/mo, respectively. But further analysis of the data revealed that the electric energy consumption of these three double-burner stoves were not significantly ($p>0.01$) different from each other since these stoves made use of the same air moving device which is a 252-watt electric blower. On the other hand, Gasifier A, which had only a 16-watt fan had significantly ($p<0.01$) the lowest electric energy consumption per month at 3.96 kW-hr.

Gas and reactor temperature. Temperature of the flue gas, producer gas and that of the reactor are presented in Table 7. Results of the evaluation revealed that the highest temperature of the flue gas collected was from Gasifier A at 154.7°C. For Gasifier D, the average temperature of the flue gas obtained was at 60.60°C followed closely by Gasifiers B and C at 54.20°C and 52.70°C, respectively. The producer gas, which was the combustible gas emitted by the gasifier stove, was measured midway the operation. Results revealed that the highest temperature recorded was with Gasifier D at 707.10°C, followed closely by Gasifiers C and B at 652.10°C and 639.20°C, respectively. The mean temperature of the producer gas emitted by Gasifier A, on the other hand, was 514.10°C. The temperature in the reactor halfway through the operation was also collected in order to determine the potential gas composition of the gasifier stove. As shown in the data, Gasifier D had the highest average temperature of the reactor at 810.5°C, while Gasifier A had the lowest at 618.1°C.

Table 5. Parameters Used in Computing the Average Thermal Efficiency (ATE) of the Rice Hull Gasifier Stoves and the Resulting ATE.

Gasifier	Ave. Initial Weight of Water	Ave. Final Weight of Water	Ave. Weight of Water Evap.	Ave. Initial Temp. of Water	Ave. Final Temp. of Water	Ave. Weight of Fuel Used	Ave. Ther. Eff (%)
	kg	kg	kg	°C	°C	kg	%
A	1.00	0.21	0.79	31.4	100.0	1.20	11.42[a]
B	1.00	0.46	0.54	29.6	100.0	2.12	4.74[b]
C	1.00	0.30	0.70	30.3	100.0	3.25	3.82[b]
D	3.00	0.58	2.42	29.6	100.0	14.7	2.86[b]

cv = 16.81%

Table 6. Parameters Used in Computing the Average Electric Energy Consumption Rate (AEECR) of the Gasifier Stoves and the Resulting AEECR

Gasifier	Ave. Voltage	Ave. Amperage	Ave. Power Load	Ave. Electric Energy Cons. Rate
	volt	ampere	kW	kW-hr/mo*
A	220	0.1	0.022	3.96[b]
B	220	0.4	0.088	15.84[a]
C	220	0.4	0.095	17.16[a]
D	220	0.4	0.081	14.52[a]

* Assumed operation: 6 hours per day at 30 days per month;
cv = 12.56%

Table 7. Average Flue Gas Temperature, Average Producer Gas Temperature, and Average Temperature of the Reactor of the Rice Hull Gasifier Stoves

Gasifier	Ave. Flue Gas Temp.	Ave. Producer Gas Temp.	Ave. Temp. of Reactor
	°C	°C	°C
A	154.70	514.10	618.1
B	54.20	639.20	742.4
C	52.70	652.10	764.1
D	60.60	707.10	810.5

Gasifier A cylindrical-type single-burner gasifier stove; Gasifier B cylindrical-type double-burner gasifier stove; Gasifier C conical-type double-burner gasifier stove; and Gasifier D conical-type double-burner gasifier stove

Potential gas composition of the producer gas. The average potential gas composition of the producer gas generated by the gasifier stoves are shown in Table 8. Data show that the carbon monoxide (CO) content of the producer gas of the four gasifier stoves is closely similar ranging from 20% to 24%. Gasifier A emitted the lowest CO (20%) and H_2 (13%) but the highest CO_2 (15%), N_2 (42%), H_2O (9%) and Ch_4

(2%). Gasifier D, on the other hand, emitted the highest CO at 24% followed by Gasifiers B and C at a similar value of 23%. All the double-burner gasifier stoves evaluated registered a similar percentage gas emission for N_2, H_2O, and CH_4 at 38%, 7%, and 0%, respectively.

Analysis of cost and returns. The gasifier stoves evaluated were compared to the use of an LPG stove in order to determine the net operating income for each gasifier stove from the savings that can be incurred from using the LPG stove. Only Gasifiers A, B, and C were analyzed since these three stoves were purposely designed for household use just like the LPG stove. Gasifier A was the cheapest among the three gasifier stoves developed for household at P5,000.00 compared to Gasifiers B and C which had a similar investment cost of P8,000.00. The fixed cost for the stoves were P9.18/day for the single-burner stove and P14.69 for the double-burner stoves. For the variable cost, Gasifier A, which utilizes a 16-watt fan, could incur P2.93 per day for rice hull and electricity consumption. Gasifiers B and C, which both use a 352-watt electric blower, have a total variable cost of P8.28 and P8.82 per day, respectively. Dividing the total cost with an assumed 3 hours operation per day would give the stove an operating cost per hour of P4.04 for Gasifier A, P7.66 for Gasifier B, and P7.84 for Gasifier C. The data further show that both Gasifiers B and C have almost similar operating expenses per hour with that of an LPG stove, hence, the yearly net operating income is very minimal especially for Gasifier B. This very slight difference in terms of operating cost for both the double-burner stoves compared to that of an LPG stove make them not economically feasible when used for household level. On the other hand, the cost analysis of operating the single-burner gasifier stove (Gasifier A) revealed an economic advantage over the use of LPG stove. The use of the single-burner stove could incur a yearly net operating income or savings over the use of an LPG stove of P4,007.70. The return or gain from using this type of stove is 80.15%. The benefit from the use of this technology for every peso spent is P0.91 with a payback period of 15 months.

Table 8. Cost and Returns of Operating the Rice Hull Gasifier Stoves

COSTS	GASIFIER STOVE			LPG
	A	B	C	STOVES
Investment Cost (IC)				
Stove	P5,000.00	P8,000.00	P8,000.00	P1,000.00
Tank				P2,500.00
Total				P3,500.00
Fixed Cost (P/day)				
Depreciation[a]	4.11	6.58	6.58	2.88
Interest on Investment[b]	3.29	5.26	5.26	2.30
Repair and Maintenance[c]	1.37	2.19	2.19	0.96
Insurance[d]	0.41	0.66	0.66	0.29
Total	P9.18	P14.69	P14.69	P6.43
Variable Cost (P/day)				
Fuel Consumption	2.42[e]	6.24[f]	6.62[g]	16.67[h]
Electricity	0.51i	2.04f	2.20k	
Total	P2.93	P8.28	8.82	P16.67
Total Cost (P/day)	P12.11	P22.97	23.51	P23.10
Operating Cost per Hour (P/hr)	P4.04	P7.66	7.84	P7.70
NOI (P/yr)	P4,007.70	P43.80	-	
ROI	80.15%	-	-	
BCR	0.91	-	-	
Payback Period	15 months	-	-	

[a]Straight line method with 10% salvage value and life span of 3 years
[b]24% of IC; [c]10% of IC; [d]3% of IC
[e] 4.83 kg/ [f] 12.48 kg/ [g] 13.23 kg rice hull per day at P0.5/kg hauling cost
[h] 1 tank LPG/30 days at P500.00/tank
[i]0.066 kw-hr/day/ [j] 0.264 kw-hr/day/ [k] 0.285 kw-hr/day at P7.73/kw-hr

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, it can be concluded that the four gasifiers developed at the APPROTECH Center significantly differ from each other in terms of fuel consumption rate, percentage char produced, fire zone rate, thermal efficiency, and electric energy consumption rate. These differences were due to variations in the diameter and height of the reactor, the size and number of burners used, and the type of air moving device employed.

Based on the results of the study, it can be concluded that among the four gasifier stoves, the cylindrical-type single-burner gasifier stove, having the least reactor size, is best in converting rice hulls to char, has the highest thermal efficiency, and utilizes the least electric energy when operated compared to the three double-burner stoves. On the other hand, the three double-burner stoves evaluated have the highest fire zone rate and use more electric energy when operated due to the 352-watt electric blower.

The potential gas composition of the gasifier stoves like carbon monoxide, hydrogen, carbon dioxide, nitrogen, water, and methane are comparable and within the range of producer gas emitted by other gasifier systems developed in other countries. Only the single-burner gasifier stove is the most economically feasible when compared to an LPG stove while the three double-burner stoves developed are not economically ideal when used in the household level due to its high investment cost and low economic return.

Based on the findings and conclusions of the study, the following are recommended to improve the design and operation of the gasifier stoves:

1. a continuous-type of loading the gasifier stove can be designed for a better and less hassle operation during cooking;
2. suitable instruments like the orsat analyzer should be used in order to properly determine the gas composition of the producer gas generated; and,
3. the gas composition of the producer gas using the orsat analyzer should be compared with the standards set by the Department of Environment and Natural Resources.

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And above all, to God Almighty for the wisdom and strength and from Whom all good things come from.

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