Design, Fabrication and Test Performance of a Modified Rice Hull Gasifier Stove[1]

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ABSTRACT

The focus of this study is to design, fabricate and test the performance of the modified rice hull gasifier stove based on the original design of Engr. Alex Belonio of the Central Philippine University.

Modification was made by increasing the size of the reactor, the part where rice hulls are placed and burned. This reactor is cylindrical in shape having a diameter of 170 mm and a height of 700 mm. The cylinder is made of an ordinary galvanized iron sheet gauge no. 16, with an annular space of 250 mm preventing heat loss in the gasifier. At the lower end of the reactor is a G.I. sheet fuel grate which is used to hold the rice hulls during gasification.

The fan assembly is the component of the stove that provides the air needed by the fuel during gasification. The fan used for the standard model is a 4-inch diameter axial-type fan that is commonly used for computers. It has a rated power input of 16 watts using a 220 volt AC line. A manually-operated rotary switch is used to control the speed of the fan which, in turn, controls the flow of gas to the burner during operation, which consists of a series of holes, 3/16-inch in diameter spaced at 1/8 inch. On top of it is a pot support that holds the pot in place upon cooking. The burner is removable for easy loading of fuel into the reactor and is set in place upon operation. Based on the actual test conducted for one loading of rice hull (1.3 kg) the stove can cook rice and fish within an average of 43.08 minutes. Likewise, cooking pork "sinigang" can only consume an average time of 35.83 minutes; and that the remaining fuel in the stove can still simmer or boil one liter of water within an average of 7.47 minutes. For an investment, the payback period of the project is six months.

Key words: *Rice hull gasifier stove, rice hull, gasifier stove, alternative energy*

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INTRODUCTION

Rice hull *(darak)* biomass waste can be found almost in any part of the Philippines. It is dumped along roadsides and some are burned to minimize its volume. In Romblon, particularly in Odiongan, reducing the volume of rice hull waste is a big problem because it clogs irrigation canals and drainage and emits foul odor when soaked in water for long periods.

One of the conventional sources of cooking fuel in the Philippines is Liquified Petroleum Gas (LPG). It is used in both rural and urban areas where the supply is accessible. Convenience is the main reason why it is widely adopted for household, as well as for food business establishments because it is easy to control and to use. However, the unpredictable increase of oil price in the international market also brought the increase of LPG fuel. The tremendous and continuous increase in LPG prices prompted household members and some business establishments to look for an alternative cooking fuel.

Wood is a good source of cooking fuel but unlike LPG, its flame is not clean and it emits a considerable amount of carbon dioxide that darkens the bottom part of pots and casserole. Charcoal, on the other hand, is also a good source of cooking fuel, especially charcoal from coconut shell it emits bluish flame like the LPG. Wood charcoal, despite its advantages over wood as fuel, is not recommended to be used for cooking because it causes forest denudation.

The soaring of LPG price, the disadvantages brought by using wood as fuel and the forest denudation caused by cutting of trees for wood and wood charcoal purposes have challenged research centers and institutions to develop technology that will utilize alternative sources of cooking fuel. The potential of biomass as alternative fuel source is one of the options to augment the needs for cooking fuel.

Gasification is a process of producing gas by burning biomass fuel. The gas produced is then ignited in the burner. For several years, gasifier stoves have been developed in many countries which may replace LPG stoves. In the Philippines, there are research institutions that developed gasification stoves and one of which is the Central Philippine University in Iloilo City.

Belonio, A. T. (2005) mentioned in his manual "*in year 2000, with the establishment of the Appropriate Technology Center (ATC) under the Department, different designs of cookstoves were developed utilizing rice hull as fuel. Through a collaborative program with The Asian Alliance of Appropriate*

Technology Practitioner Inc. (APROTECH ASIA) and the Asia Regional Cookstove Program (ARECOP), the Author was given an opportunity to attend the Training on Wood Gasifier Stove at the Asian Institute of Technology in Thailand in 2003. In this training, an Inverted Down-Draft (IDD) or Top-Lit Updraft (TLUD) wood gasifier was demonstrated by a Sri Lankan participant, who found out that such wood gasifier is promising to be used for rice hulls as fuel without experiencing the problems encountered in the previous designs of rice hull gasifier".

Engr. Belonio permits other researchers to improve on his work as seen here: *"Permission is hereby granted for the reproduction of this material, in whole or in part for educational, scientific, or development-related purposes provided that (a) full citation of the source is given and (b) notification in writing is given to the author".*

With the preceding premise, the researcher got interested in the gasification technology of Engr. Belonio in making use of the rice hull biomass waste in our locality. In September 2009, after a series of communication with Engr. Alexis T. Belonio, the proponent was granted the authority to adapt the rice hull gas stove technology. Adaptors form was sent and within the same month, the proponent started modifying the design of Engr. Belonio.

OBJECTIVES

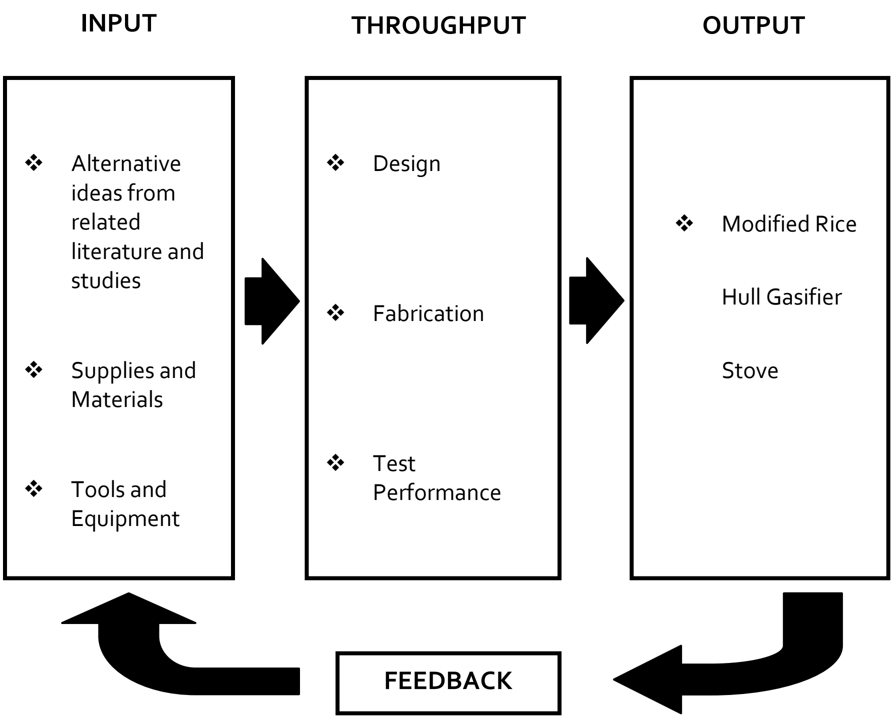
This study was conducted to design, fabricate and test the performance of the modified rice hull gasifier stove. Specifically, the objectives of the study are the following:

1. To help address problems along climate change and mitigation through a study that would utilize cheap and at times problematic material as rice hull;
2. To modify the design of the components of a rice hull gasifier stove, namely:
    a. the gasifier stove reactor
    b. the burner
3. To fabricate the rice hull gasifier stove based on the new design parameters/ standards.
4. To test the performance of the machine to determine the following:

a. Start up time
b. Operating time
c. Total operating time
d. Fuel consumption rate
e. Specific Gasification rate
f. Combustion Zone rate
g. Boiling time of water
h. Cooking time (Rice)
i. Frying of Fish
j. Cooking time of Pork Sinigang
k. Sensible heat
l. Latent heat
m. Power input
n. Power Output
o. Thermal Efficiency
p. Heat Energy Input
q. Percent char

5. To determine the payback period for an investment.

CONCEPTUAL FRAMEWORK



The conceptual model of the study is shown in the form of a paradigm in Figure 1. It utilizes the input, throughput and output model. The INPUT of the study consists of alternative ideas from related literature and studies, supplies and materials, tools and equipment, and cost of construction of the project. The THROUGHPUT covers the different processes involved in the development of the model namely: designing, fabrication and testing. The OUTPUT is the modified rice hull gasifier stove.

SIGNIFICANCE OF THE STUDY

The modified rice hull gasifier stove technology has been found to have the following qualities:

- It can significantly reduce the cost of household spending for conventional fuel sources such as LPG, electricity, kerosene, wood and wood charcoal.
- It can help reduce the problem of rice hull disposal which contributes a lot to environmental pollution, especially the burning of rice hull along roadside.
- It can help preserve the forest by reducing the cutting of trees for the production of wood fuel and wood charcoal.

MATERIALS AND METHODS

Materials

Table 1. Materials used in the project

Qty	Specs.	Description
1 pc	# 16	Galvanized Iron Sheet
1 pc	4" x 4"	Computer Fan (5V, AC)
1 kg	Ordinary	Welding Rod
1 pc		Rotary Switch (dimmer)
1 pc	½"x½"x20'	Square bar
1 pc	Ordinary	Male plug
2 m	# 16	Electric wire

Tools and Equipment Used

1. For Fabrication
    - Electric arc welding machine
    - Rubber mallet
    - Hammer
    - Gas welding machine
    - Grinding machine
    - Tin Snip

- Hacksaw
- Anvil
- Sandpaper
- Sheet roller
- Bench shear

2. For Testing
    - Spring Balance
    - Measuring cup
    - Thermometer
    - Stopwatch

Methods

Design Parameters Used in Modifying the Rice Hull Gasifier Stove

To come up with the modified rice hull gasifier stove, the following parameters/ standards below were used by the researcher, thus, deviating from the original design of Engr. Belonio.

Table 2. Design Requirements/Standard used in the modified rice hull gas stove

Design Requirement	**Value**
The heat requirement to cook food	810 kcal/kg
Fuel consumption rate	1.5 kg/hr
Reactor Diameter	170 mm
Height of the reactor	700 mm
Time to consume rice hull	0.999 hrs.
Air needed for gasification	1.7172 m^3/kg
Air Velocity	2.19 cm/sec
Resistance to air flow	0.35 m H_2o

Fabrication Procedure

The fabrication of the gasifier stove is simple. Accuracy in measuring and cutting of sheets is an important aspect since measurement is in millimeters. It is necessary however, to procure all the supplies and materials needed in the fabrication of the machine. Shop tools and equipment had to be prepared. It was also necessary to contact an expert welder prior to fabrication. The procedure is as follows:

1. A layout of the various parts of the stove starting from the reactor cylinder to fuel grate and support leg was done.
2. The various plates were cut to the required sizes.
3. The plate was rolled for the inner cylinder to make a shell reactor.

4. A hole was drilled for the outer cylinder.
5. Two circular plates were cut for the top flange and the base plate of the outer cylinder.
6. Another circular plate for the bottom flange of the reactor inner cylinder was cut.
7. The bottom flange at the base of the inner cylinder was welded.
8. A circular plate was made to form a grate.
9. Holes were drilled in plate.
10. The grate inside the inner cylinder was welded on the same plane with the bottom flange.
11. The inner cylinder assembly was inserted into the outer cylinder.
12. The bottom flange was welded to the outer cylinder. Then, the top flange was welded to the inner and outer cylinders.
13. The base plate was welded at the bottom of the outer cylinder.
14. A square hole was cut at the lower end of the outer cylinder for fan casing attachment.
15. A plate was cut for fan casing assembly.
16. The casing was welded to the outer cylinder.
17. A round iron bar for support legs was cut.
18. The iron bar was bent to form angular support legs
19. The legs were welded to the outer cylinder equidistant to each other.
20. A round iron bar for the handles was cut.
21. The iron bar was bent to form handle for proper gripping.
22. The handles were welded to the outer cylinder with one at the top end and the other at the lower end, slightly above the fan casing.
23. A circular plate for the burner and plates for the sleeve were cut.
24. Holes were drilled on top of the plate to form burner.
25. Two rounds of holes were formed, one row at the inner ream and another at the outer ream of the burner plate.
26. Plates for the pot support were cut such as rings, stands and handle.
27. The pot support ring was formed first, then the pot support stands to the rings were welded, starting from the inner to the outer rings.
28. The stand of the burner plate was cut to form the entire burner structure.
29. The pot support handle was welded to the outer ring.

Data Collection and Computation

The following test parameters were used in evaluating the performance of the rice hull gasifier stove:

1.	Start up time	10.	Frying of Fish
2.	Operating time	11.	Cooking Pork Sinigang
3.	Total operating time	12.	Sensible heat
4.	Fuel consumption rate	13.	Latent heat
5.	Specific Gasification rate	14.	Power input
6.	Combustion Zone rate	15.	Power Output
7.	Boiling time of water	16.	Thermal Efficiency
8.	Cooking time (Rice)	17.	Heat Energy Input
9.	Cooking time (Rice)	18.	% char

1. Start-Up Time – is the time required to ignite the rice hulls and consequently to produce combustible gas. This parameter is measured from the time the burning pieces of paper are introduced to the fuel in the reactor until combustible gas is produced at the burner.

2. Operating Time - is the duration from the time the gasifier produced a combustible gas until no more gas is obtained from the burning rice hulls.

3. Total Operating Time- is the duration from the time the rice hull is ignited until no more combustible gas is produced in the stove. Basically, it is the sum of the start-up time and the operating time of the stove.

4. Fuel Consumption Rate (FCR) – is the amount of Rice Hull fuel used in operating the stove divided by the operating time. This is computed using the formula,

$$FCR = \frac{\text{Weight of Rice Hull Fuel Used (kg)}}{\text{Operating Time (hr)}}$$

5. Specific Gasification Rate (SGR) – is the amount of rice hull fuel use for unit area of reactor. This is computed using the formula,

$$SGR = \frac{\text{Weight of Rice Hull Fuel Used (kg)}}{\text{Reactor Area } (m^2) \times \text{Operating Time (hr)}}$$

6. Combustion Zone Rate(CZR)- is the time required for the combustion zone to move down the reactor. This is computed using the formula,

$$CZR = \frac{\text{Length of the reactor (m)}}{\text{Operating Time (hr)}}$$

7. Boiling Time- is the time required for the water to boil starting from the moment the pot is placed on the burner until the temperature of water reaches 100°C.

8. Sensible Heat – is the amount of heat energy required to raise the temperature of water. This is measured before and after the water reaches the boiling temperature and computed using the following formula:

$$SH = Mw \times Cp \times (Tf - Ti)$$

where:

SH - Sensible Heat, Kcal
Mw - Mass of water, kg (1kg/liter)
Cp -Specific Heat of Water, 1 kcal/kg-°C
Tf – Temperature of water at boiling, Approx 100 °C
Ti- Temperature of water before boiling, 27-30 °C

9. Latent Heat – is the amount of heat energy used in evaporating water and is computed using this formula below:

$$LH = We \times Hfg$$

Where:

LH-Latent Heat, Kcal
We- weight of water evaporated, kg
Hfg- latent heat of water, 540 Kcal/kg

10. Heat Energy Input- is the amount of heat energy available in the fuel and is computed using this formula:

$$QF = WFQ \times HVF$$

Where:

QF- heat Energy Available in Fuel, Kcal
WFU-weight of fuel used in the stove,kg
HVF- heating value of fuel, Kcal/kg

11. Thermal Efficiency – is the ratio of the energy used in boiling and in evaporating water to the heat energy available in the fuel and is computed using the formula:

$$TE = \frac{(QT)}{(FCR)(HVF)}$$

Where:

TE – the stove thermal efficiency, %
QT = the total heat needed in cooking, kcal/hr
HVF = heating value of fuel, kcal/kg
FCR = Fuel consumption rate, kg/hr

12. Power Input – is the amount of energy supplied to the stove based on the amount of fuel consumed and is computed using this formula:

$$Pi = 0.0012 \times FCR \times HVF$$

Where:

Pi - Power Input, kW
FCR –Fuel Consumption Rate, Kg/hr
HVF – Heating value of fuel, Kcal/kg

13. Power Output- is the amount of energy released by the stove for cooking and is computed using this formula:

$$Po = FCR \times HVF \times TE$$

Where:

Po- Power output, kW
FCR- fuel consumption Rate, Kg/hr
HVF- heating Value of Fuel, Kcal/kg
TE- thermal efficiency,%

14. Percentage (%) Char Produced- is the ratio of the amount of Char produced and the amount of rice hulls used and can be computed using the formula:

$$\%\ Char = \frac{\text{Weight of Char (kg)}}{\text{Weight of Rice Hull Used (kg)}} \times 100$$

Testing Procedure

The following procedures below are the basic steps done to test the rice hull gas stove:

1. Preparation of materials.
   a. Rice hulls were gathered.
   b. The commodities to be tested were procured from the market: rice, fish, water and pork.
   c. The rice hulls needed were hauled into place.

   d. The gasifier stove was cleaned.
   e. Rice hulls were weighed.
2. Gasifying
   a. A full load of rice hulls was put inside the cylinder.
   b. A piece of paper was lit and dropped to the top of the cylinder. The fan was switched until the top portion of the rice hull was fully burned.
   c. The burner was placed into the top of cylinder head.
   d. The smoke had come out of the burner. Waiting varies.
   e. The burner was lit.

How to Use the Stove

1. Cooking time

   For Water
   a. Pour a liter of water into the kettle and place it on the burner.
   b. Start timing.
   c. Wait until it boils.
   d. Record the time.

   For Rice
   a. Put 1 kg of rice into the pot and wash it.
   b. Add a desired amount of water and place it on the burner.
   c. Start timing.
   d. Wait until it is cooked.
   e. Record the time.

   For Pork
   a. Prepare the meat and the spices.
   b. Boil two liters of water with some of the spices and start timing.
   c. Put the pork and wait until it becomes tender.
   d. Put the vegetables and other spices.
   e. Wait until it is cooked.
   f. Record the time.

   For Fish
   a. Prepare the frying pan and put it on the burner.
   b. Put the cooking oil and start timing.
   c. Start frying.
   d. Wait until it is cooked.
   e. Record the time.

Note: Repeat the procedure in all commodities in five replications.

RESULTS AND DISCUSSIONS

Project Cost

The cost of the fabricated rice hull gasifier stove was based on the expenditures for supplies and materials, labor and other expenditures. The total cost of the project is summarized below.

Table 3. Project Cost (PhP)

Bill of Materials for Fabrication	2,654.00
Contract Labor(cutting, laying-out and welding)	1,000.00
Administrative Cost	700.00
Incidental Expenditure	146.00
TOTAL PROJECT COST	**4,500.00**

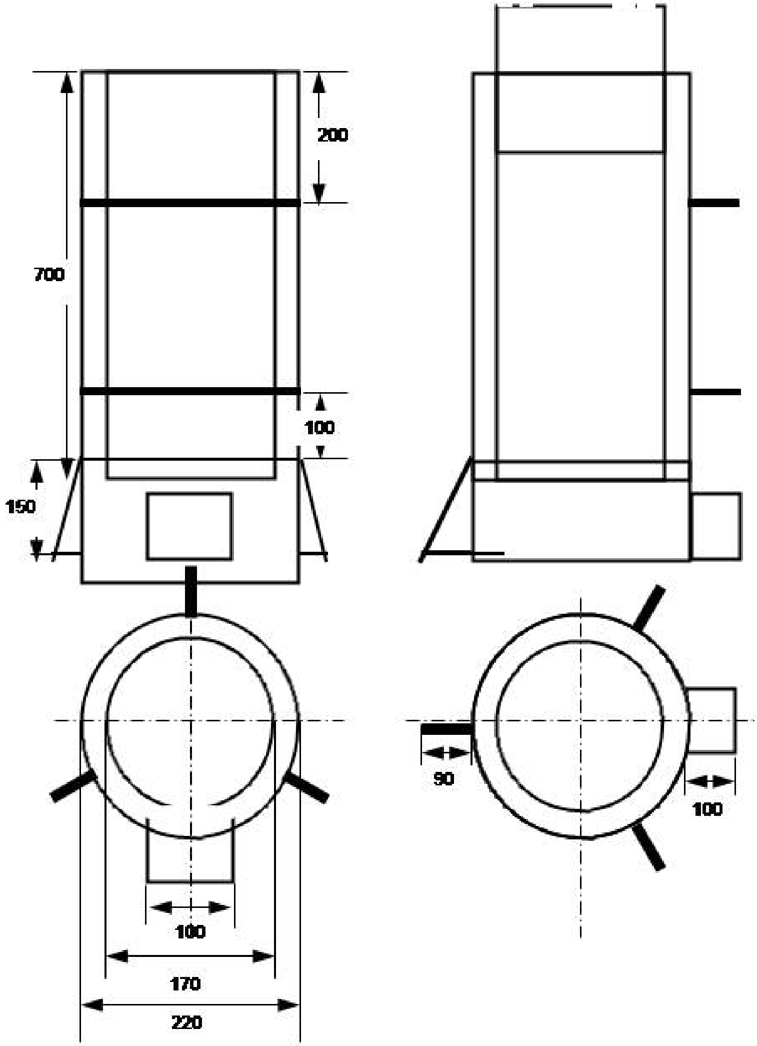
The total cost of the rice hull gasifier stove amounted to P 4,500.00 as shown in Table 3. If mass production will be undertaken, the cost of production will be lesser since two gasifier stoves can be made in one full length of GI sheet.

The gasifier stove reactor is the component of the stove where rice hulls are placed and burned with limited amount of air. This reactor is cylindrical in shape having a diameter of 170 mm and the cylinder with the height of 700 mm. The latter is made from an ordinary galvanized iron sheet gauge no. 16 and is provided with an annular space of 250 mm that serves as insulation in order to prevent heat loss in the gasifier. At the lower end of the reactor is a fuel grate also made of G.I. sheet, which is used to hold the rice hulls during gasification.

The Fan Assembly

The fan assembly is the component of the stove that provides the air needed by the fuel during gasification. It is fastened to the cylinder, to directly push the air into the column of rice hulls in the reactor. The fan used for the standard model is a 4-inch diameter axial-type fan that is commonly used for computers. It has a rated power input of 16 watts using a 220 volt AC line. A manually-operated rotary switch is used to control the speed of the fan which in turn, controls the flow of gas to the burner during operation.

THE MODIFIED GASIFIER STOVE REACTOR



The Burner

The burner converts the gas coming out from the reactor to a bluish flame. It consists of series of holes, 3/16-inch in diameter spaced at 1/8 of an inch, where combustible gas is allowed to pass through. The secondary holes located at the periphery of the burner are used to supply the air necessary for the combustion of gases. On top of the burner is a pot support that holds the pot in place while cooking. The burner is removable for easy loading of fuel into the reactor and is set in place during operation.

RESULTS AND DISCUSSION

The data below is the cooking performance of the modifier rice hull gasifier stove.

Table 4. Cooking performance of the gasifier stove

Trials	Rice	Fish	Water	Pork
1	15.08	28.27	7.13	35.00
2	15.67	26.93	8.03	35.08
3	16.18	25.57	7.08	37.00
4	14.75	29.00	8.00	36.08
5	15.08	27.75	7.12	36.00
Average	15.58	27.50	7.47	35.83

1. It was found out that one full load (¾ of the cylinder) of rice hull weighed 1.3 kilograms.
2. Start up time for gasifier is 1 minute, operating time is 46.63 minutes and the total operating time is 47.63 minutes.
3. The designed rice hull gasifier stove can cook 1 kg of rice and 1 kg of fish in the combined time of 43.08 minutes.
4. The designed rice hull gasifier stove can cook 1 kg of pork mixed with vegetables within 35.83 minutes and the remaining heat can simmer a liter of water.

The data below are the comparative result of the performance of the gasifier based on the design concept or standard and the actual results of the test.

Table 5. Comparative Results of Data

Test Parameters	Based on Design Standards	Results of Actual Tests
Fuel Consumption rate	1.59 kg/hr	1.64 kg/hr
Specific gasification rate	70 kg/m^2-hr	55.55 kg/m^2-hr
Combustion zone rate	0.7777 m/hr	0.882 m/hr
Cooking time- 1 kg of rice	15 minutes	15.35 minutes
Frying fish – 1 kg	26 minutes	27.50 minutes
Cooking time – 1 kg of pork	Not considered	35.83 minutes
Boiling Time – 1 liter of water	13 minutes	7.47 minutes
Sensible heat	73 kcal	73 kcal
Latent heat	Not computed	151.2 kcal
Thermal efficiency	17%	9.1%

Heat energy input	3,000 kcal	3,900 kcal
Power input	5.724 kW	5.904 kW
Power output	810.9 kW	447.72 kW
Percentage of (%) char	No data	19.23%

Economic Viability

To determine the viability of the project, it is imperative to determine the time when the cost of investment in a certain project may be recovered. In this project, payback period analysis is applied to determine the number of months or years the investment can be recovered. The shorter span of time to recover the investment, the better is the project.

The following data were gathered based on actual interview with the LPG retailers. It is assumed that within one month, one 11-kg tank of Liquified Petroleum Gas (LPG) could be consumed.

Expenses incurred in using LPG	
Prevailing average refill price of LPG	P 870.00
Transportation cost	30.00
Total cost in using LPG	900.00
For Rice Hull Gasifier Stove	
Power consumption per month in using computer fan	12.75
Transportation cost	132.00
Cost of Match box	6.00
Total cost in using gasifier	150.75
Cost of Rice Hull Gasifier Stove	P 4,500.00

Payback Period

$$\text{Payback period} = \frac{\text{initial investment}}{\text{savings month}}$$

where: initial investment = P 4,500.00
savings per year = LPG cost – Gasifier cost
= P 900.00 – P 150.75
= P 749.25

$$\text{Payback period} = \frac{\text{P } 4{,}500}{\text{P } 749.25/\text{month}}$$

$$= 6 \text{ months}$$

It was found out that an investment for a gasifier stove can be recovered in six months.

SUMMARY AND CONCLUSIONS

Modification was made on the original stove of Belonio (2004) by increasing the size of the reactor. The gasifier stove reactor is the component of the stove where rice hulls are placed and burned with limited amount of air. This reactor is cylindrical in shape having a diameter of 170 mm and the cylinder with the height of 700 mm. Such is made from an ordinary galvanized iron sheet gauge no. 16 and is provided with an annular space of 250 mm that serves as insulation in order to prevent heat loss in the gasifier. At the lower end of the reactor is a fuel grate also made from G.I. sheet, used to hold the rice hulls during gasification.

The fan assembly is the component of the stove that provides the air needed by the fuel during gasification. The fan used for the standard model is a 4-inch diameter axial-type fan that is commonly used for computers. It has a rated power input of 16 watts using a 220 volt AC line. A manually-operated rotary switch is used to control the speed of the fan which, in turn, controls the flow of gas to the burner during operation.

The burner converts the gas coming out from the reactor. It consists of series of holes, 3/16 inch in diameter spaced at 1/8 of an inch. On top of the burner is a pot support that holds the pot in place while cooking. The burner is removable for easy loading of fuel into the reactor and is set in place during operation.

Based on the actual tests conducted, the following data were obtained. During the conduct of the test, the proponents observed that in 1 loading of rice hull (1.3 kg) the stove can cook rice and fish in an average time of 43.08 minutes. It was also observed that cooking pork sinigang consumes only an average time of 35.83 minutes and the remaining fuel in the stove can simmer or boil 1 liter of water at an average time of 7.47 minutes. As computed, the payback period for utilizing the rice husk gas stove is 6 months.

It was concluded that the modified rice hull gasifier stove is a great help in the reduction of rice hull biomass waste. For a family that consumes a kilo of rice and a kilo of fish per meal, the rice hull gasifier stove can be an alternative cooking stove.

RECOMMENDATIONS

Based on the findings and conclusions previously stated, the following courses of action have been recommended:

1. That a rice husk gas stove gasifier be used as an alternative cooking stove in rural areas where rice husk is abundant.
2. That the technology be extended to the community not only in the municipality of Odiongan, but in the entire province of Romblon or even nationwide.
3. That continuous research endeavor be conducted in similar technology using indigenous materials.

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