DESIGN AND PERFORMANCE OF A HOUSEHOLD-SIZE CONTINUOUS-FLOW RICE HUSK GAS STOVE [1/]

Alexis T. Belonio, Project Director (atbelonio@yahoo.com)
Emmanuel V. Sicat, Project Leader (evsicat@yahoo.com)
Francisco D. Cuaresma, Assistant Project Leader (fdcuaresma@yahoo.com)
CLSU-CRHET Rice Husk Project
College of Engineering, Central Luzon State University
Science City of Munoz, Nueva Ecija, Philippines

ABSTRACT

This paper describes the design and performance of a household-size continuous-flow rice husk gas stove aimed to provide rural families with an alternative device for cooking. By gasifying rice husk, a clean burning gaseous fuel is derived for cooking.

The stove, basically, has a 12-cm diameter by 30-cm high fuel reactor where rice husks are burned and subsequently converted into combustible gases. A plate-type gas burner with 40 pieces 4-mm diameter holes set the gas into flame, which is eventually used for cooking. The char pan, which is located directly beneath the reactor, collects burned rice husks for subsequent disposal. The air needed for gasification is supplied by a12-volt, 0.12-Amp DC fan. The stove operates following the principle of moving-bed down-draft reactor in which rice husks are fed at its top end and the char is discharged from the bottom end. Combustible gases, consisting of carbon monoxide and hydrogen, are generated from the reactor within 4 minutes from the time the fuel is ignited. The gas temperature leaving the reactor is measured at the range of 90 to 110°C, whereas, the temperature beneath the pot ranges from 250 to 400°C. Results of performance tests of the stove further revealed that a liter of water at 27°C can be boiled in the stove within 5.0 to 7.6 minutes and 2 liters of water can be boiled within 10.4 to 15.2 minutes. The amount of rice husks used to fuel the stove varies from 1.07 to 1.12 kg per hour with computed specific gasification rates of 90 to 102 kg/hr-m^2. The thermal efficiency of the stove was measured from 18 to 25% using water boiling test. The thermal power output, on the other hand, varies from 0.69 to 1.01 kWt.

The stove can be fabricated using local materials and labor with selling price of P2,000.00 per unit including the fan and AC-DC adoptor. With proper operation and maintenance, the life span of the stove is estimated to last for 2 years. Investment for the stove can be recovered within 2 to 3 months.

[1/] Paper submitted for presentation at the 61st Annual National Convention of the Philippine Society of Agricultural Engineers and 9th International Agricultural Engineering Conference and Exhibition to be held at Dapitan Gymnasium, Dapitan City, Zamboanga del Norte, Philippines on April 25-29, 2011.

INTRODUCTION

The cost of fuel for domestic cooking is continuously increasing at a fast rate. At present, the price of conventional fuel is at the range of P45 to P70 per kg. Conventional cooking stoves, such as gas and liquid burners, are convenient to use and to operate but they are almost unreachable to many nowadays causing the people, particularly in villages, to adopt biomass and wood as fuel for their cooking need. Although the use of traditional wood and biomass stoves are affordable, however, the excessive smoke and particulate emissions and the uncleanness in the surroundings during cooking hinder many households to continue in their use of these stoves. It was reported by the World Health Organization, moreover, that indoor pollution caused by too much smoke emission in the traditional burning wood and biomass stoves results in about 1.6 million deaths per year in developing countries due to chronic respiratory diseases [10].

On the other hand, rice husk, a by-product in processing rice, is an abundant waste that can be found in many areas in the country. In the past, rice husk is disposed by burning along road sides and/or by dumping on river banks. About 2 million metric tons of rice husks are available annually with enough potential energy as fuel for domestic household [3]. Per kilogram of rice husk, about 3,000 kcal of heat is made available for cooking [7]. Despite of the varied applications or usage of rice husks, the abundance in supply of this waste material can still warrant as an alternative source of energy for the rural people.

Gasifying biomass, like rice husks was found to be a good alternative to provide households with low-cost but clean source of energy for cooking [1 & 2]. By limiting the amount of air used in burning rice husks, combustible gas that is rich in carbon dioxide and hydrogen are produced which is almost similar to liquefied petroleum gas fuel in terms of physical characteristics [3]. Several studies revealed a stove that operates on gasification has low particulates as well as CO_2 emission [1, 2, & 9]. Among the various gasifier stoves tested on spot during the US-ASEAN New-Generation Stove Workshop at Asian Institute Technology in Thailand, the rice husk gas stove obtained the lowest black carbon emission of about $50ug/m^3$ of gas [6].

In 2005, a top-lit downdraft type rice husk gasifer stove operating in a batch mode was developed at Central Philippine University in Iloilo City [3]. The advantage characteristic of the stove has caused the widespread acceptance of the technology by the people not only in the Philippines but also in other rice producing areas in the world like Indonesia, Vietnam, India, and other countries in Asia, Africa as well as Central and South America [4&8]. Because of the differences in cooking practices and need by households, a rice husk gas stove that operates in a continuous mode was designed and developed.

This paper describes the design and performance of a household-size continuous-flow rice husk gas stove aimed to provide households a simple and clean burning stove for cooking. The comparative operating cost analysis against LPG and kerosene burners is also presented in this paper.

METHODOLOGY

Design Preparation

The design of the stove was based on the principle of bottom-lit moving-bed down-draft type rice husk gasifier, which was recently developed for industry application [5]. Instead of multiple locations provided for fuel ignition, only one ignition point was considered in the present design. The size of the reactor was scaled down to nearly 1 kWt, just enough for a family with 3 to 4 members. The amount of air needed to gasify rice husks was computed using an equivalence ratio of 0.3 to 0.4 with stoichiometric air for rice husk of 4.7 kg air per kg of fuel as recommended by Dr. Albreacht Kaupp [7].

After finalizing the conceptual design of the stove, a 3D AutoCAD drawing was prepared to ensure consistency throughout the different assemblies. A 2D drawing was also prepared to serve as a guide in the fabrication of the different parts of the stove.

Fabrication

Prior to fabrication, the design drawing was discussed with the Fabricator to gather input to further simplify the construction of the stove to make the unit durable and affordable.

The stove was fabricated at BMC in Pavia, Iloilo, Philippines. Further revisions and improvement of the design was done at BEST-Enterprise at the Science City of Munoz, Nueva Ecija, Philippines. Regular shop visits were made until construction of the stove was completed.

Performance Testing and Evaluation

The final proto-type of the stove was tested using water boiling tests. Series of tests were conducted at BMC shop as well as at CLSU-CRHET Rice Husk Project Office at CLSU College of Engineering. During testing, fresh rice husks were used as fuel for the stove. One liter and 2 liters of water were boiled in the stove for more than an hour. In each test, the time required to boil water was determined. During the test, the temperature of water was measured at 2-minute interval using a bimetallic thermometer. The gas temperatures as well as the flame temperatures beneath the pot were recorded every 10 minutes using a digital thermometer with type K thermocouple wire sensor. The time to ignite rice husk fuel and the time to generate combustible gases were also taken in each test. The amount of water remaining in the pot was also measured in each operation. The following parameters were determined during the tests: (1) Fuel consumption rate; (2) Specific gasification rate; (3) Thermal efficiency; (4) Power output; and (5) Percentage char produced.

Operating Cost Analysis

The cost of operating the stove was determined based on the investment cost, which is the actual selling price of the stove, by shop fabricators such as BMC and BEST-e who are currently producing and selling the stove. The investment cost and the costs incurred for the rice husk fuel and electrical consumptions were computed on a daily and on hourly bases. A comparative operating cost analysis was done and the savings derived in using the rice husk gas stove over conventional stoves was determined. The time required to recover the investment for the stove was also computed.

RESULTS AND DISCUSSIONS

Design Description of the Stove

The stove, as shown in Figure 1 below, is a scaled-down version of the continuous-flow moving-bed rice husk gasifier operating on a bottom-lit down-draft mode. It generally consists of the following components, namely: (1) Fuel Hopper; (2) Fan; (3) Fuel Reactor; (4) Gas Duct; (5) Gas Burner; (6) Pot Support; (7) Support Legs; (8) Char Pan; and (9) Push Rod. The fuel hopper holds the rice husks in place before they are fed into the reactor. Rice husks are gasified in the reactor by burning them with limited amount of air supplied by a 12-Volt, 0.12-Amp computer fan. The reactor is made of a 1.2-mm GI sheet and has a diameter of 12 cm and a height of 30 cm. The gas duct, where combustible gases are diverted into, is made of 10-mm diameter cylinder with a height that is slightly higher than the reactor and the fuel hopper. On top of the gas duct is the plate-type gas burner having 40 pieces 4-mm diameter holes. The char pan and the push rod are used to facilitate the removal of char during operation. The entire structure is supported by four pieces of inclined legs.

Figure 2 shows the schematic of the operation of the stove. As shown, rice husks are fed and gasified in one cylinder and the gas is diverted into the other cylinder which is subsequently burned at the gas burner. Rice husks are ignited by dropping burning pieces of paper on top of the gas duct. Air is supplied to the burning rice husks by switching ON the fan, which can either be energized by an AC-DC calculator adoptor, by a 12-volt battery,

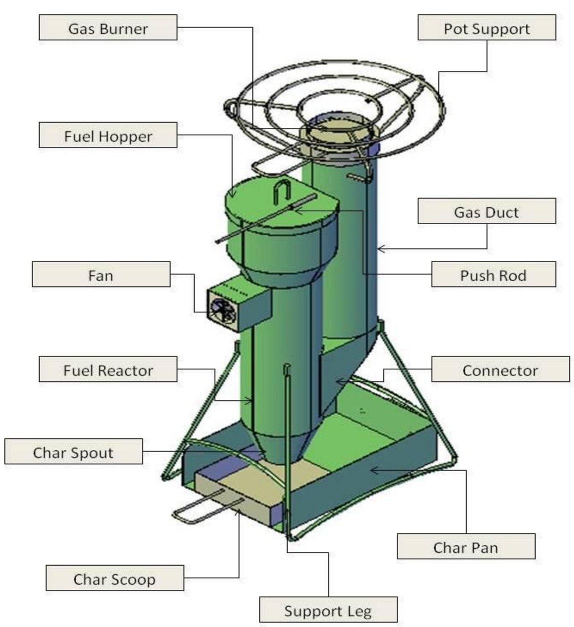

Figure 1. The Household-Size Continuous-Flow Rice Husk Gas Stove showing Its Various Parts.

Reactor	12 cm ø x 30 cm high
Gas Duct	10 cm x 40 cm
Mode of Operation	Continuous
Principle	Bottom-Lit Down-Draft Gasifier
Fan Size	6 cm x 6 cm
Fan Rating	DC 12 volt, 0.12 Amp
Burner Type	Plate with 40 pcs 4-mm holes
Loading Capacity	0.50 kg

Table 1. Design Specifications of the Rice Husk Gas Stove.

Figure 2. Schematic Drawing and Pictorials of the Operation of the Stove.

or by a 12-volt 5-watt solar panel. As the char is removed from the bottom of the reactor by simply sweeping the push rod sideways, the reactor is replenished with fresh rice husks from the hopper. The char needs to be removed from time to time to ensure a sustained burning of rice husks in the reactor. Note that untimely removal of char will hamper the production of gas.

Fabrication of Stove

The stove can be fabricated in a small shop or even in a backyard shop using local materials and labor. Galvanized iron sheet and bars are used as materials for the stove. To eliminate rolling of sheets, a galvanized iron or conduit pipe can be used as a replacement. Four units of the stove can be built out of one standard size 1.2-m wide by 2.4-m long metal sheet. For these four units of stoves, two pieces of round bars are needed for the legs and handle as well as pot holder. One person can build one stove in one day. Figure 3 shows the pictorial of the fabrication and production of the stove in a `small backyard shop.

Figure 3. Fabrication of the Stove in a Small Backyard Shop.

Test Performance

Results of the performance tests and evaluation revealed that the stove performs well as per design. As shown in Table 2 below, rice husk consumption of the stove is at a rate of 1.07 to 1.12 kg/hr, depending on the degree of char removal and on the amount of air supplied to the fuel. Ignition of rice husks is achieved after a minute of dropping

Table 2. Performance of the Stove.

Parameters	Run 1 – Low	Run 2 – Medium	Run 3 – High
Fuel Consumption Rate (kg/hr)	1.07	1.09	1.12
Ignition time (minutes)	1	1	1
Gas Generation Time (minutes)	5	4	3
Time to Boil Water (minutes)			
1 liter	7.6	6.4	5
2 liters	15.0	12.1	10.4
Gas Temperature (°C)	90	97	100
Temperature Beneath the Pot (°C)	250	347	400
Specific Gasification Rate (kg/hr-m^2)	90	99	102
Thermal Efficiency (%)	22	25	18
Char Production Rate (kg/hr)	0.32	0.32	0.34
Thermal Output (KWt)	0.69	0.78	1.01

pieces of burning paper inside the gas duct and it takes about 3 minutes before combustible gases are generated at the burner. It was found out during the test, however, that in order to facilitate ignition of rice husks and to shorten the generation of combustible gases, the fan which supplies the needed air in burning rice husks must be set at 12 volt to have enough air for combustion thus minimizing smoke emission. It was also observed that wet rice husks produces more smoke than dry ones. It was found out, moreover, that production of gas is enhanced once there is enough amount of burning char in the reactor.

Bringing a liter of water into a boil in the stove takes 5 to 7.6 minutes, depending on the intensity of the flame. The higher the fan voltage setting, the stronger the flame produced; hence, shortening the boiling time of water. Using 2 liters of water, on the other hand, the time required to boil such amount of water ranges between 10.4 to 15 minutes. Figure 4 shows the temperature profile of boiling water in the stove. Temperature measurements showed that gas temperature, which was taken at the gas duct using a thermocouple wire sensor, varies from 90 to 100°C; whereas, the temperature measured beneath the pot varies from 250 to 400°C. The specific gasification rate of the stove varies from 90 to 102 kg/hr-m^2. This rate, however, is below the ideal rate to properly operate the gasifier in a continuous mode. Furthermore, the thermal efficiency of the stove varies from 18 to 25%. This value is still acceptable since the gas burner operates without a heat shield or a skirt in keeping the heat concentrated at the bottom of the pot. The char production rate or the amount of burned rice husk

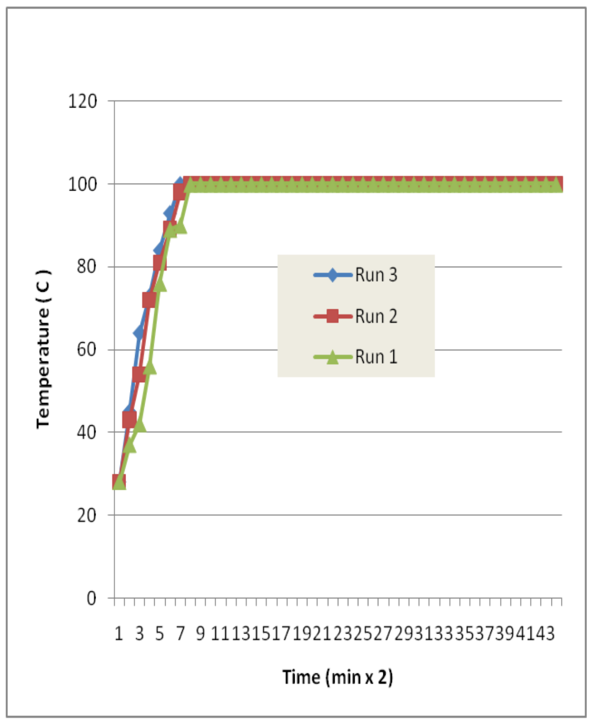

Figure 4. Water Temperature Profile of Boiling 2 liters of water in the stove.

produced varies from 0.32 to 0.34%. In addition, the computed thermal output of the stove is at the range of 0.69 to 1.01 kWt.

Operating Cost, Savings, and Payback Period

The stove requires an investment of P2,000.00 complete with a 12-volt fan and an AC-DC adoptor. A typical household with 3 to 4 members will requires an average of one

Table 3. Operating Cost Analysis of the Stove.

	RHG	Kerosene	LPG
Investment Cost IC (P)			
Stove	2,000.00	350	600
Hose, Regulator, and Tank			2,500.00
Sub-Total	2,000.00	350.00	3,100.00
Fixed Cost (P/day)			
Depreciation 1/	2.47	0.43	2.55
Interest on Investment 2/	1.32	0.23	2.04
Repair and Maintenance 3/	0.55	0.10	0.85
Insurance 4/	0.16	0.03	0.25
Sub-Total	4.49	0.79	5.69
Variable Cost (P/day)			
Fuel 5/	2.25	37.50	31.50
Electricity 6/	0.15	-	-
Sub-Total	2.40	37.50	31.50
Total Cost (P/day)	6.89	38.29	37.19
Utilization (Hr/day)	3	3	3
Operating Cost (P/hr)	2.30	12.76	12.40
Savings P/hr	-	10.46	10.10
P/day		31.39	30.30
P/month		941.79	908.92
P/year		11,458.50	11,058.50
Payback Period (Year)		0.17	0.18

1/ Straight line with 10% depreciation and 2, 2, 3 years life span for RHGS, Kerosene, and LPG stoves, respectively

2/ 24% of IC

3/ 10% of IC

4/ 3% of IC

5/ Rice Husk Gasifier – @ P7.50 per sack of rice husk (10 kg per sack) for 3-day consumption; Kerosene – @ P45.00 per liter and 0.25 liter consumption per hour; and LPG – @ P770.00 per 11 kg and consumption of 0.15 kg/hr

6/ P10 per kw-hr

kilogram of rice husks per hour cooking. The cost of electricity in operating the stove is very minimal since the fan used only consumes about 0.005 kw-hr. The computed fixed cost for the stove is P4.49 per day while the variable costs, which are the costs incurred for the rice husk fuel plus the small amount of electricity consumed in running the fan, is P2.40 per hr. Considering a 3-hour operation per day, the computed operating cost per hour for the stove is only P2.30. Comparing the rice husk gas stove with that of conventional stoves, consumption of kerosene is assumed at 0.25 liter per hour while for LPG is 0.15 kg per hour. Investment cost for the kerosene stove is cheaper than that of LPG stove, which is slightly higher than that of the rice husk gas stove due to the cost of tank, hose, and regulator. The computed fixed costs for kerosene and LPG stoves are P0.79 and P5.69 per day, respectively. The cost of fuel used per hour is quite expensive for the conventional stoves giving P37.50 and P31.50 for kerosene and LPG fuel, respectively. The cost to operate the kerosene stove per hour is computed at P12.76 while P12.40 for LPG. The households who will opt to use the rice husk gas stove can have a daily savings of P10.46 over the use of kerosene stove and P10.10 over the use of LPG stove. For the period of one year, a total savings of P11,458.50 can be derived by households over the use of kerosene stove and P11,058.50 over the use of LPG. The investment for the rice husk gas stove can be recovered with 2 to 3 months.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, the rice husk gas stove performs accordingly with design. It can satisfactorily provide combustible gases for continuous operation of more than one hour domestic cooking. It can be energized either by direct connection into an AC-DC calculator adoptor in areas where grid is available or by the use of a 12-volt battery with 12-volt 5-watt solar panel in off-grid situation. With proper operation, smoke is almost completely eliminated and clean combustible gases for cooking is achieved. The stove can be fabricated even in a backyard shop using metal sheets and bars employing the local people. The price of the stove is affordable to many and households can generate substantial savings from the use of biomass fuel over the use of conventional fuel. Investment can be recovered within a short period of less than a year.

It is likewise recommended that further improvement on the rice husk gas stove must be done to cater the specific needs of households in terms of comfort and convenience in cooking operation.

REFERENCES

[1] Anderson, P. S, Belonio, A. and Reed, T. Top-Lit Updraft (T-LUD) Gasification Advances of 2005. ETHOS 2006 Seminar (January 27-29). Session 4 – Technology Design and Performance http://www.repp.org/discussiongroups/resources/stoves

[2] Anderson, P.S., Wendelbo, P., Reed, T.B., and A.T. Belonio. Super-Clean Combustion of Solid Biomass Fuels in Affordable TLUD Cookstove. Paper presented during the International Conference. Beyond Firewood: Exploring alternative fuels and energy technologies. New Delhi, India. December 11-12, 2008.

[3] Belonio, A. 2005. Rice Husk Gas Stove Handbook. Appropriate Technology Center, Central Philippine University. 141pp. www.crest.org/discussiongroups/resources/**stove**s/Belonio/Belonio_**gas**ifier.pdf

[4] Belonio, D, et al. The MJ Rice Husk Gas Stove. Paper presented at VINASILIC, Ho Chi Minh City, Socialist Republic of Vietnam on February 2, 2009.

[5] Belonio, A.T., Belonio, D.A.H., and L. Larano. A Continuous-Flow Rice Husk Gasifier for Thermal Applications. Paper presented during the 10th PCIERD Regional S&T For a and Competition held at FNRI Training Room, DOST Compound, Bicutan, Taguig, Metro Manila, Philippines on February 26, 2010.

[6] Hansen, T. Measurements of Source of Emission, Personal Exposure, and Ambient Condition. Paper presented at the ASEAN-US Next Generation Cook Stove Workshop, Asian Institute of Technology, Bangkok, Thailand. November 16-20, 2009.

[7] Kaupp, A. (1984). Gasification of Rice Hull: Theory and Praxix. Federal Republic of Germany: GATE/GTZ. 303pp.

[8] Minang, B., Belonio, A., and D. Atmowidjojo. The MJ Single-Burner Rice Husk Gas Stove. PT Minang Jordanindo Approtech. Jakarta Selatan, Indonesia. 2007.

[9] TEENET. Cooking options in the developing countries. http://www.send.ait.ac.th/teenet/cooking.htm. 3pp.

[10] WHO. 2005. Indoor Pollution and Household Energy Monitoring. Workshop Resources. World Health Organization. France. 13pp.

ACKNOWLEDGMENT

The authors wish to acknowledge the Almighty God who is the source of Wisdom and Knowledge in the design of this stove making rice husks as one of the clean source of fuel for cooking. The Rolex Award for Enterprise 2008, Geneva,Switzerland, and the Tech Awards 2010, San Jose, California, USA for the funding support in the development and extensive dissemination of the information about the rice husk gas stove technology. The BMC, BEST-e, 6Ms Ag Biosystem Eng Enterprises and Consultancy Corporation, and Kanvar Enterprise for their support in producing and marketing the stove locally in order to reach the target market, especially the rural households.

Appendix 1

Pictorials of Two Models of Continuous-Flow Rice Husk Gas Stove on Commercialization

Appendix 2

LIST OF LOCAL STOVE COOPERATING MANUFACTURERS AND DISTRIBUTOR
(As of April 2011)

Company	Status
BMC, Purok 1, Pavia, Iloilo, Philippines	Produces variety of rice husk gasifier stoves ranging from small batch-type to large scale continuous-type gasifiers
Biomass Energy System Technology Enterprises (BEST-e), Science City of Munoz, Nueva Ecija, Philippines	Produces continuous-type stoves and gasifiers for paddy dryer
6M's Ag Biosystem Eng Enterprises and Consultancy Corporation, Quezon City, Metro Manila, Philippines	Produces batch-type gasifier stove and continuous-type gasifier stove
Green Asia Energy Corporation, Davao City, Philippines	Produces continuous-type rice husk gasifier for thermal applications and will start mass production of the continuous-type rice husk gas stove
Kanvar Enterprises, Sucat, Paranaque City, Metro Manila, Philippines	Distributes batch- and continuous-type rice husk gasifier stoves