DESIGN AND EVALUATION OF A DRUM-TYPE RICE HULL CARBONIZER AND THE MANUALLY-OPERATED BRIQUETTE MOLDER FOR BIOCOAL FUEL PRODUCTION AND FOR AGRICULTURAL APPLICATIONS

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ABSTRACT

A drum-type rice hull carbonizer and a manually-operated briquette molder were designed and evaluated at the Department of Agricultural Engineering, Central Philippine University (CPU), Iloilo City from June 1999 to April 2000. The carbonizer was made of salvage petrol-drum opened at the top where rice hull is loaded for carbonization. A steel cover with T-chimney was provided to serve as exhaust for burned gases. A 2 1/2-in. electric blower was provided for the carbonizer to supply air necessary for combustion. The briquette molder, on the other hand, is made of steel pipe having a diameter of 15.5 cm and a height of 13.5 cm. Twelve pieces of 2-cm diameter shafting were distributed centrally in the molder cylinder to create holes on the briquette necessary for proper combustion. Results showed that the carbonizer has a loading capacity of 22.5 to 33.75 kg of rice hull per batch. Carbonization time ranged from 43 to 65 minutes. The percentage CRH produced per load is 30.7% and an average of 16 pieces biocoal fuel is produced per load in the carbonizer. Physical properties of CRH produced from the carbonizer were found out to be of higher water holding capacity, with 3.49 to 3.72 times of the original weight. Each biocoal fuel weighs about 484.5 to 531.1 g and has a heating value of 2,407.7 kcal/kg. The fuel can be ignited within 2 to 5 minutes and sustain a burning time of 45 to 65 minutes. No significant effect was observed when using CRH as soil conditioner for growing radish. However, the use of CRH as feed supplement for Cobb broilers showed that birds fed with commercial feeds mixed with 5% CRH significantly increased their feed consumption which resulted in an increase in their live weight gain. Cost analysis showed that for an investment cost of P5,700.00 and with a capacity to produce 128 pieces of biocoal fuel per day, the cost to produce a piece of biocoal fuel is P1.80. At a selling price of P3.00 per piece and at an operating period of 8 hours per day, 20 days per month, and 10 months per year, the return on investment is 539 percent. Payback period is 1.85 months and the benefit-cost ratio is 0.65.

INTRODUCTION

Background

The cost of fuel for domestic cooking keeps on increasing at a fast rate. This can be attributed to the limited supply of wood and wood charcoal in the market as a result of continued cutting of trees.

According to Beagle (1978), conversion of plentiful supply of organic solid wastes into a clean energy form provides an opportunity to expand the energy source while reducing the pollution associated with waste disposal. Also, Erickson and Prior (1990) noted that the briquetting of agro-residues is one of a number of ways wherein the disposal of huge volume of agricultural waste can be solved by converting it into a useful product such as fuel and for other agricultural uses.

Basically, rice hull is a by-product of milling rice. It is primarily used in the Philippines as heat source for domestic cooking as well as for drying (Waddle, 1985).

According to Yamashita and Hao (1978), rice hull is about 18 to 20 percent of rough rice by weight. Kaupp (1984) found out that rice hull has a bulk density ranging from 100 to 110 kg/m3. It can be pyrolized at a temperature of 250-500 (C and produced carbonized char of about 32%. To completely burn rice hull, an air requirement of 4.7 kilogram of air per kilogram of hull is necessary. They further added that rice hull can be converted to carbonized form through gasification using an optimum equivalence ratio of 0.32 of the stoichiometric air.

At the International Rice Research Institute, Jeon, et. al. (1986) designed a cylindrical rice hull carbonizer using brick materials for the production of carbonized rice hull. The char collected from the carbonizer were briquetted using soil as binder and were used as source of heat for direct-fired dryers. The design and construction of a biocoal plant were carried out by Belonio and Paranpan (1995) in Barotac Nuevo for Tamasak Multipurpose Cooperative. They found out that the plant can produce biocoal fuel at a rate of 700 to 900 biocoal tablets per day. Test of the performance of the fuel showed that it can provide sufficient heat for cooking for a typical size family and can be produced at a cost of about P1.46 per piece.

In Indonesia, studies conducted on the use of CRH on various crops (Fagi, 1989) showed that the grain and root yield of corn and soybean were improved with the use of CRH as compared with the control samples. Some of the characteristics of CRH as enumerated by Fagi are as follows: (a) it has lots of micropores which increases the capacity to hold water, gas, nutrient, and microorganism in the soil; (b) it can improve soil acidity due to its weak alkali characteristics; (c) it can improve soil physical properties such as air ventilation and soil temperature; (d) it can replenish soil nutrient such as salicylic acid, carbon, iron, and potassium; and (e) it can accelerate root penetration of crops in the soil.

Another study was conducted in Japan by scattering CRH in the amount of 300 to 400 kg per acre before plowing. It was found out that a 10 to 20 percent increase in rice yield was observed for the field with scattered CRH than for the fields tilled with conventional method. Also, mixing the soil with 50 to 100 percent CRH can produce 20 to 30 more cucumber during harvest period of 30 days as compared with those of the control samples. Moreover, animals fed with 10 percent CRH can improve animal digestibility (Kansai Corporation).

Rice hull, which is an agrowaste material, is very much abundant in the Philippines. Annually, about 1100 to 1600 metric tons of rice hull is produced in the country. A kilogram of rice hull contains 3000 kilocalories of heat and can be further increased if it is carbonized. In other countries like Japan and Indonesia, CRH is used not only for heat production but also for agricultural applications such as soil conditioner and feed supplement for farm animals.

In 1987, the CPU College of Agriculture, Department of Agricultural Engineering has embarked on its research and development effort to improve technologies utilizing rice hull as fuel. Rice hull stoves, ranging from single to multiple burners, were designed and tested. The process of converting rice hull to a carbonized form was also carried out to develop a biocoal fuel for domestic cooking. Since there is a growing demand for alternative fuel sources and a massive campaign in the use of indigenous material sources to increase production while reducing cost, there is a need to explore and develop a technology that will utilize rice hull. A low-cost rice hull carbonizer having a dual purpose to produce CRH for biocoal fuel as well as for agricultural applications would be an alternative technology that would generate income for less privileged households or farmers in rural community. Converting agrowaste rice hulling to a usable product would be one of the several noble solutions to counteract energy shortage and waste pollution problem while uplifting the living status of rural people.

Objectives of the Study

The general objective of the study is to design and evaluate a drum-type rice hull carbonizer and a manually operated briquette molder for biocoal fuel production and for agricultural applications.

The specific objectives are:

1. To design a low-cost rice hull carbonizer and a briquette molder appropriate for rural household or farmer's use;
2. To evaluate the performance of the carbonizer and briquette molder and test their products produced as fuel for cooking, as soil conditioner, and as supplement for animal feed; and
3. To make a cost-return analysis of operating the carbonizer and the briquette molder for biocoal fuel production.

Time and Place of the Study

This study was conducted at the Department of Agricultural Engineering, College of Agriculture, Central Philippine University, Iloilo City from June 1999 to April 2000.

METHODOLOGY

Design and Fabrication

The rice hull carbonizer and the briquette molder were designed at the Department of Agricultural Engineering, College of Agriculture, Central Philippine University, Iloilo City. In the design, the criteria considered were the loading capacity, cost, and ease of maintenance. The machines were fabricated in a backyard welding shop at Lapaz, Iloilo City employing a local welder.

Performance Evaluation of the Machines

The carbonizer was tested according to the amount of rice hull consumed, amount of carbonized rice hull produced, and operating time per load. On the other hand, the briquette molder was tested according to the number of pieces of biocoal fuel produced per unit time, ease of molding, as well as the quality of briquette molded.

Testing of CRH for Domestic Cooking and Agricultural Applications

The CRH produced from the carbonizer were tested based on the physical as well as thermal properties. Physical properties such as the bulk density, angle of repose, angle of friction, and the water holding capacity were determined during the conduct of the study. Other physical properties of the biocoal fuel produced as volume, weight, density, thickness, and diameter were also evaluated. Proximate analyses of fuel were also determined during the test.

In testing CRH as soil conditioner, samples of it was used in growing radish at a rate of 1 to 4 kg per meter square. The number of functional leaves, plant height, root length and diameter, and yield were determined during the study. Separate experiment using CRH as feed supplement for Cobb broiler was also conducted. Commercial feeds mixed with CRH at 5, 10, 15 percent levels were tested on the effect on the feed consumption rate and the live weight gain of the birds.

Instrumentation

In measuring the weight of rice hull sample and carbonized rice hull produced, a 10-kg Fuji Weighing Scale was used in the study. Operating time was determined using a DT stopwatch. Physical properties of rice hull char and briquetted fuel were determined using Ohaus Triple Beam Balance. Measurements of the diameter and length of samples of radish were also recorded with the use of the Venier caliper. The amount of feed consumed and the live gain weight of Cobb broilers were also taken with the 10-kg weighing scale.

RESULTS AND DISCUSSIONS

Design Description of the Machines

Figure 1 shows the design of the rice hull carbonizer. As shown, the machine consists of the following major components: (a) the carbonizing chamber, (b) the cover and the chimney, (c) the blower and the air pipe, and (d) the support frame.

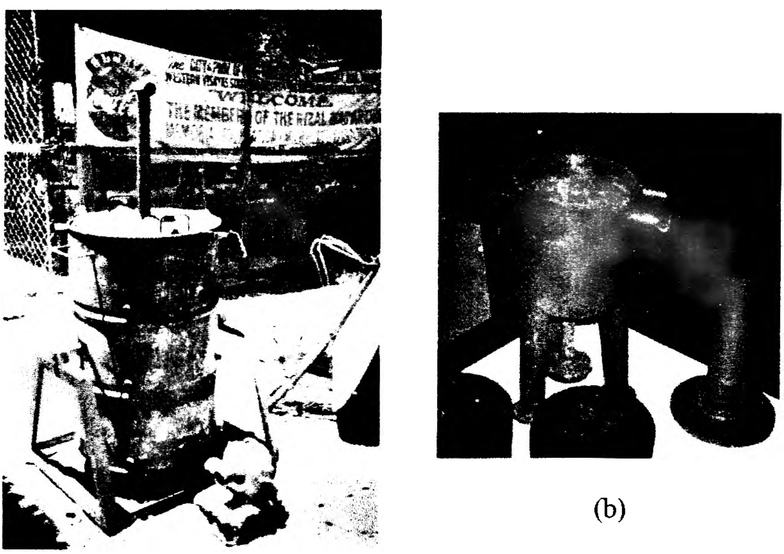
The carbonizing chamber is made of a salvage 200-liter capacity petrol drum. The top of the drum is completely opened for ease of loading and unloading of the rice hull. Twelve (12) air holes made of 3/4-in. diameter BI pipes were provided on the surface wall of the drum to provide airflow during carbonization. These pipes were installed equidistant with each other to uniformly supply the needed air. A cover and a 2-in. diameter T-chimney was provided on top of the drum to act as smoke stock and to create necessary suction of air during carbonization. At the base of the drum is a 2-in. diameter air pipe to distribute combustion air delivered by the electric blower. In order to facilitate the discharge of CRH, the drum is elevated so that it can be tilted for char disposal.

Figure 2 shows the briquette molder. As shown, the briquette molder has a diameter of 15.5 cm and a height of 13.5 cm. It is made of 6-in. diameter schedule 40 BI pipe. Inside the molder are 12 pieces of shafting having a diameter of 3/4 in. necessary to create holes for proper combustion of biocoal fuel. The molder is supported by three (3) BI pipe legs to elevate it and at the same time to provide ease of removing the molded fuel.

Performance of the Machines

Table 1 shows the results of the tests on ricehull carbonizer. Test run conducted on April 2, 2000 showed that 22.5 kilogram of rice hull was completely carbonized in the carbonizer within 43 minutes yielding about 6.75 kg of carbonized rice hull. In the test conducted on April 28, 2000 23.25 kg rice hull was carbonized in the carbonizer within 45 minutes yielding about 8.25 kilogram char. Similarly, the test conducted on May 4, 2000 showed that 33.75 kilogram rice hull was completely carbonized in the carbonizer within 63 minutes yielding 9.19 kilogram char. Based on the results of the three tests, the computed capacity of the carbonizer in Table 2 ranged from 51 to 53 kilogram per minute while the computed percentage CRH produced ranged from 2 7.2 to 35.0 percent. It was also observed that in operating the carbonizer, one person is enough to do the loading and firing of rice hull.

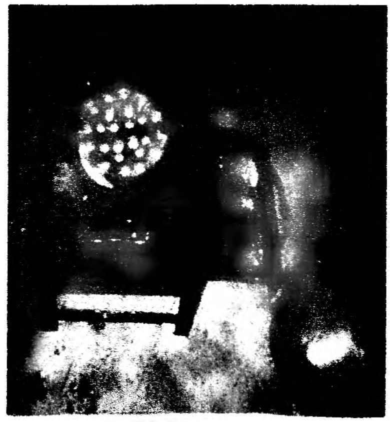
In molding operation, results in Table 3 showed that two persons can do the molding of biocoal fuel for an average of two minutes per piece of fuel. This includes loading, manual pressing by pounding with mallet, and removal of molded briquette by the use of a counter press.



(a) (b)

Figure 1. Pictorial View of the Machines: (a) The Drum-Type Rice Hull Carbonizer and (b) The Manually-Operated Briquette Molder.

(a)



(b)

Figure 2. The Pictorial View of Biocoal Fuel: (a) Fuel Samples, and (b) Burning Biocoal Fuel in the Stove.

Table 1. Results of Testing of the Drum-Type Ricehull Carbonizer Conducted During the Months of April and May, 2000.*

Test Run	Weight of Rice Hull (kg)	Carbonization Time (min)	Weight of Carbonized Rice Hull Produced (kg)
April 25, 2000	22.50	43	6.75
April 28, 2000	23.25	45	8.25
May 4, 2000	33.75	63	9.19

* Separate tests showed that it requires 7 to 10 days to finish carbonization and burning of rice hull.

Table 2. Computed Capacity and the Percentage CRH Produced in the Carbonizer.

Replication	Carbonizer Capacity (kg/hr)	Percentage CRH Produced (%)
1	31.2	30.0
2	30.6	35.0
3	31.8	27.2
Ave	31.2	30.7

Table 3. Molding Time of Blended CRH Biocoal in the Briquette Molder.

Replication	Weight of CRH* (kg)	No. of Pieces of Biocoal Fuel Produced	Total Molding Time (min)	Molding Time per CRH Biocoal Fuel (min)
1	6.93	13	26	2.00
2	8.21	16	19	1.19
3	9.64	19	36	1.89
Ave	8.26	16	27	1.69

* Weight of moisture and gelatinized starch included.

Product Performance

As shown in Table 4, the bulk density of CRH at loose condition is at an average of 371.0 kg/m3. After it was ground, the CRH obtained an average bulk density of 855.3 kg/m3. Measurement of the angle of repose of CRH range from 40 to 50 degrees from the horizontal while the angle of friction is at the average of 30 to 32 degrees. On the other hand, test on the water holding capacity showed that when CRH is dipped in the water, it has a capacity to hold moisture of about 3.49 to 3.72 times of its original weight. In table 5, the biocoal fuel showed that each piece weighs about 484.5 to 531.1 grams. The average volume was computed to be 1509.5 cm3 . The average diameter of the fuel is 15.5 cm while the thickness is 8 cm. Proximate analysis showed that the biocoal fuel have an average moisture content of 6.6%, volatile matter content of 25.3%, ash of 39.83%, sulfur of 0.064%, and a fixed carbon of 39.15%. The heating value of the fuel is 2407.7 kcal/kg. It can be ignited within 2.5 minutes using 8 burning pieces of paper. Total operating time to completely burn the fuel ranges from 45 to 65 minutes sufficient enough to carry out one cooking operation for a typical family.

Results of the tests presented in Table 6 that used different levels of carbonized rice hull (1 to 4 kg/m2) as soil conditioner on radish showed that there is no significant results obtained on the number of functional leaves, plant height, average root length and diameter, percentage marketable and non-marketable root and yield as compared with control samples. Utilizing CRH as feed supplement for broilers as presented in Table 7 showed that birds fed with commercial feeds mixed with 5 to 15 percent CRH has a significantly higher feed consumption and gain in live weight per bird as compared with the control birds which were fed pure commercial feeds. Birds fed with 5 percent CRH were significantly lower in feed efficiency per birds as compared with other treatments.

Operating and Cost-Return Analyses

The investment requirement to fabricate the drum-type carbonizer is P2,700.00 and the manually operated briquette molder is P2,500.00. While other materials needed to prepare the gelatinized starch is P500.00. As shown in Table 8, the fixed costs which include depreciation, interest on investment, repair and maintenance, and insurance total to P7.77 per day. On the other hand, the variable cost per day is P223.56. This includes the cost of the starch for 10 g per briquette at P9.00 per kg, electricity cost of the blower at 0.176 kW operating for 8 hours at a cost of P5.00 per kW, the cost of fuel in preparing a gelatinized starch at a cost of P5.00 per preparation, and the cost of labor for two persons at P100.00 per person, at 8 hours working period per day. With the capacity of producing 128 briquettes per day, the cost of producing a piece of briquette is P1.80.

Cost-return analysis in Table 9 showed that considering a selling price of P3.00 per briquette and operating the machines in 20 days per month and for 10 months in one year, the net income that can be derived in one year is P30,720.00. The computed return of investment is 539% while the payback period is 1.85 months. The benefit cost ratio is 0.65.

Table 4. Physical Properties of CRH

Bulk Density	
Loose	371.0 kg/m^3
Ground	855.33 kg/m^3
Angle of Repose	40 - 50 degrees
Angle of Friction	30 - 32 degrees
Water Holding Capacity	3.49 - 3.72

Table 5. Physical and Thermal Properties of Biocoal Fuel

Weight per Fuel	484.5 - 531.1 g
Volume of Fuel	1509.5 cm^3
Diameter of Fuel	15.5 cm
Thickness of Fuel	8 cm
No. of Holes	12
Hole Diameter	2 cm
Moisture Content	6.6%
Volatile Matter	25.53%
Ash	39.84%
Sulfur Content	0.064%
Fixed Carbon	39.15%
Heating Value	2407.7 kcal/kg
Ignition Time	2 - 5 min
Burning Time	45 - 65 min
Time to boil 2 liters of water	[illegible]1 - 35 min

Table 6. Results of Test Conducted Using Different Levels of CRH on the Growth of Radish

CRH Level (kg/m^2)	No. of Functional Leaves	Plant Height at Harvest (cm)	Root Length (cm)	Root Diameter (cm)	Yield (kg/plot)
0	13.87	22.98	20.51	4.03	8.01
1	14.07	22.45	22.22	4.06	8.02
2	13.67	22.09	21.92	4.01	7.94
3	13.70	21:73	20.49	3.96	7.89
4	13.57	21.79	20.14	3.82	7.82

Note: Results of ANOVA showed no significant difference among treatment means at 5% level of significance.

Table 7. Results of Test Using CRH as Feed Supplement for Cobb Broilers

Amount of Char Used	Feed Consumption (kg/bird)	Live Weight Gain (kg/bird)	Feed Efficiency per Bird	Calculated Return
0	2.77^{b}	1.38^{b}	2.00^{b}	34.94
5	2.98^{a}	1.61^{a}	1.85^{b}	51.83
10	3.03^{a}	1.52^{a}	2.00^{b}	46.84
15	3.15^{a}	1.43^{b}	2.22^{a}	37.22

Note: *a* and *b* denote significant differences among treatment means at 5% level.

Table 8. Operating Cost Analysis Producing Biocoal Fuel Using the Drum-Type Carbonizer and the Manually Operated Briquette Molder

Investment Cost (IC)	
Carbonizer	P 2,700.00
Briquette Molder	2,500.00
Others (pan, cooking pot)	500.00
Total	P5,700.00
Fixed Cost	
Depreciation 1/	P2.07/day
Interest on Investment 2/	3.75/day
Repair and Maintenance 3/	1.56 /day
Insurance 4/	0.46/day
Total	P7.77/day
Variable Cost	
Starch 5/	P11.52/day
Electricity 6/	7.04/day
Fuel for cooking 7/	5.00/day
Labor 8/	200.00/day
Total	P223.56/day
Total Cost	P231.34/day
Capacity 9/	128 pieces/day
Production Cost	P1.80/piece

1/ Straight line at 10% salvage vale and life span of 7 years
2/ 24% of the IC
3/ 10% of IC
4/ 3% of IC
5/ 10 g of starch per briquette @ P9.00/kg starch
6/ 0.176 kW, 8 hours per day operation @ P5.00/kw-hr
7/ P5.00 wood fuel per day for cooking gelatinized starch
8/ 16 biocoal tablets per load, 8 loads per day operation

Table 9. Cost Return Analysis of Producing Biocoal Fuel Using the Drum-Type Rice Hull Carbonizer and the Manually Operated Briquette Molder

Investment Cost	P5,700.00
Fixed Cost per Year	P2,838.60
Variable Cost per Year	P44,712.00
Total Operating Cost per Year	P47,550.60
Net Income per Year	P30,720.00
Return on Investment	539%
Payback Period	1.85 months
Benefit Cost Ratio	0.65

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, the following are concluded:

The rice hull carbonizer is a simple and low-cost technology for converting rice hull carbonized form. It can sufficiently carbonize rice hull at the capacity that can be handled by individual rural household.

The briquette molder can be manually operated with ease of producing biocoal fuel.

The CRH produced was found to have good physical and thermal properties. It can be used to produce biocoal fuel for domestic use and has high water holding capacity suitable for retaining moisture necessary for crop growth. It is also suitable as feed supplement for growing Cobb broilers.

To further improve the rice hull carbonizer, it is recommended that the exhaust fumes produced from the carbonizer which is harmful to the environment must be utilized for cooking gelatinized starch as well as for drying biocoal fuel. Testing of CRH using other crops and livestock should be explored.

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