Performance of The Continuous-Type Rice Hull Carbonizer as Heat Source in Food Product Processing

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Abstract: This study evaluated the potential of the PhilRice-developed continuous rice hull (CtRH) carbonizer as heat source for processing food products so as to provide additional income opportunities. Specifically, it aimed to (a) determine the actual amount of heat that can be tapped from the operation of the CtRH carbonizer using two fabricated heat recovery attachments (HRAs) and (b) test and evaluate the performance of each of the HRAs, and (c) identify potential food products that can be processed by the carbonizer when equipped with the HRAs. Boiling test results showed that, while producing biochar at a rate of 9.6 kg/hr, the maximum amount of heat that can be tapped from the CtRH carbonizer is equivalent to 15 kW. On the other hand, results of the oven test showed that the temperature distribution inside the oven compartment is uniform at different tray layers. The highest temperature attained inside the oven chamber was 250 °C. Thus, the heat generated from the CtRH carbonizer offers a lot of potential benefits for the farmers.

Keywords*:* biochar, carbonizer, food processing, heat, rice hull

Introduction

There is a growing interest in the potential uses of biochar in agricultural systems, in particular, for carbon sequestration and productivity benefits. The production and utilization of biochar in farming has been considered as a way of reducing emissions and increasing sequestration of greenhouse gas while delivering immediate benefits through improved soil fertility and increased crop production [1]. Biochar as a material is defined as "charcoal for application to soils" [2]. Its combined production and use is considered a carbon-negative process, a process that removes carbon from the atmosphere [3].

In the Philippines, under an integrated and diversified system of farming called *Palayamanan,* now becoming popular and being practiced by Filipino farmers nationwide, biochar from rice hull (carbonized rice hull or CRH) is commonly used as soil conditioner or as main ingredient in the production of organic fertilizers. It is also used as bedding or absorbent material to facilitate urine and manure collection as well as help eliminate foul odor in poultry, swine and livestock. Once saturated, it is collected and applied to the soil as fertilizer [4].

The conventional practice of processing biochar from rice husk is accomplished by partial burning just enough to char the rice husk but not to completely burn it into ash. This is usually accomplished using a batch-type carbonizer [4]. In this practice, the heat generated during the carbonization process, being exothermic, is just wasted. To maximize the benefits derived from the production and utilization of biochar, PhilRice came up with a new system of processing rice hull into biochar using the continuous rice hull (CtRH) carbonizer wherein the heat generated during its operation can be recovered for various practical applications in the farm.

This study evaluated the potential of the CtRH carbonizer as heat source for processing food products that would provide additional income opportunities for the farmers, as a strategy to make them more resilient climate change impacts [5]. Specifically, it aims to:

a. determine the actual amount of heat energy that can be tapped from the operation of the CtRH carbonizer using two fabricated heat recovery attachments (HRAs),
b. test and evaluate the technical performance of each of the HRAs, and
c. identify potential food products that can be processed from the carbonizer when equipped with the HRAs.

Materials And Methods

The CtRH carbonizer used in the study

Figure 1 shows the CtRH carbonizer used in the study. This is generally made of 2mm thick BI metal sheets with a body dimension of 0.8 m x 0.8 m x 1.5 m (length, width, and height, respectively). The carbonizer has a fully-covered hopper to make it able to operate during windy conditions. The hopper houses the inverted V-partition (made of the same 2mm thick metal sheet used for the sidings) which forms an empty space once the hopper is filled with rice hull. This empty space serves as the combustion chamber where combustion takes place as the ambient air mixes with the pyrolytic gases and other products of incomplete combustion. It is also where the material to be carbonized is initially ignited during the start of the operation. The inverted V partition is designed to be easily detachable to facilitate repair or replacement since it is exposed to extreme heat may easily deteriorate. The 52mm diameter air inlet allows entry of the ambient air and is also detachable to facilitate firing during the start of operation or re-igniting the combustion chamber when the flame is extinguished while in the middle of operation [6]. The carbonizer is equipped with 125mm diameter x 3,658mm long chimney fabricated from 2mm thick metal sheet.

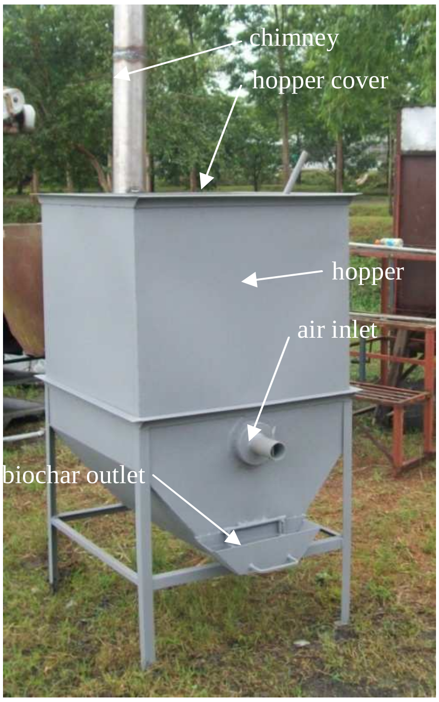

Figure 1. The CtRH carbonizer.

To start the operation, small amount of kerosene is sprinkled into the combustion chamber and then ignited. Once the flame has become vigorous and stabilized, the air inlet is put in place. The heat generated at the combustion chamber carbonizes the rice hulls in the immediate vicinity. Pyrolysis and partial combustion takes place within the vicinity of the combustion chamber and progresses radially. Because of the suction effect of the chimney, the pyrolytic gases and those generated due to partial combustion (most of which are combustible) are drawn into the combustion chamber where they get combusted as the ambient air, coming in via the air inlet, mixes with them. In most cases, smokeless emission is observed at chimney.

The opening at the bottom allows harvesting of the charcoal once the carbonization zone has already reached the bottom part of the machine. The carbonizer can accommodate 6 sacks (approximately 10 kg per sack) of rice hull with an average capacity of 24.2 kg/hr [6]. It is mainly designed for rice husk carbonization but various test runs proved that it can also carbonize rice straw, coconut husks and wood although minor adjustments need to be done in order to minimize smoke emission.

The heat recovery attachments

1. Cooking attachment. The cooking attachment (Fig. 2) is mostly made of 2mm thick BI sheet metal which forms the 37 cm diameter cooking chamber. The cooking chamber is insulated with ferrocement, i.e. cement reinforced with 25cm mesh wire. It has tripod legs (~90.0 cm wide) equidistant to each other which supports the whole cooking attachment. It is simple in construction and operation. During carbonization process, the heat generated by the carbonizer enters through the inlet of the cooking chamber and exits to the chimney. This heat is utilized for cooking. The cooking attachment is equipped with a regulating valve which controls the entry of the hot gases into the cooking chamber to regulate the heat.

Figure 2. The cooking attachment of the CtRH carbonizer showing the mounted cooking vessel.

2. Oven attachment. The oven attachment used in the study (Fig. 3) was composed of main parts namely: a heat chamber that accommodates eight 370mm x 500mm x 40mm trays where the products to be cooked or baked are placed, a 125mm square inlet tube with a regulating valve, and a 125 mm diameter chimney. The oven was 1935mm in height (excluding the height of the chimney), 740mm in length and 470mm wide. To save on cost of materials, it was mostly made of ferrocement, using five layers of 25mm wire mesh as reinforcement. The heat chamber, had walls made of 2mm thick stainless steel plate and was provided with door hinged at one edge of the wall. It had also an exhaust, where the chimney was directly connected to provide suction effect thus enabling the hot gas to pass through it once the regulating valve is opened.

   Pre-heating was first done to bring the temperature of the heat chamber to the desired level. This was done by igniting the rice hull at the carbonizer’s combustion chamber until a vigorous flame was established. The heat generated by the carbonizer then heated up the walls of the oven’s heat chamber which in turn caused the products inside the heating chamber to be cooked. The purpose of the oven in the study is for utilizing heat in the processing of high value food products.

Figure 3. The oven attachment of the CtRH carbonizer.

Evaluation of the carbonizer as heat source

1. Water boiling test (WBT). In this test, the procedure for testing stove reported by DeFoort et al. [7], an updated version of the WBT version 3.0 by Balis et al. [8], was used. This test was conducted using a commercially-available stainless steel cooking vessel which was filled with 30L of water and brought to a full boil. The cooking vessel was placed at the cooking attachment when the temperature at the carbonizer's combustion chamber has stabilized**.** To measure the water temperature, K type thermocouple wires were placed in the cooking vessel. The temperature of the water from the start until it boiled was automatically recorded every minute using a data logger where the thermocouple wires were connected. The temperature sensing probe was positioned at the center, roughly 5cm above the bottom of the cooking vessel (Fig. 4). This test was intended to measure how well energy was transferred from the fuel to the cooking pot [8]. Thus, during testing, the regulating valve that controls the entry of the heat generated by the CtRH carbonizer was placed at different settings: fully-opened, three-fourth (3/4) opened, half-opened (1/2), one-fourth (1/4) opened and closed position.

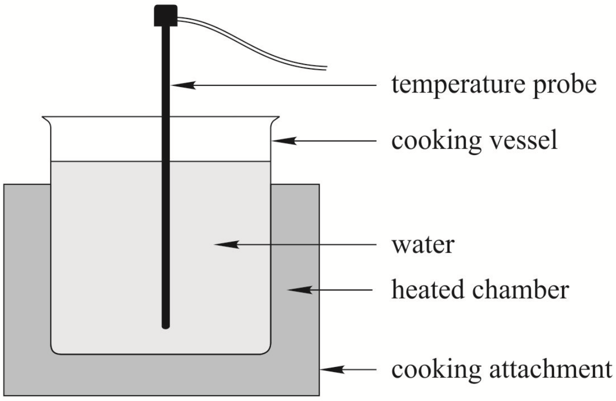

Figure 4. Schematic diagram showing the set – up of the water boiling test with the TC probe inside the pot.

For each valve setting and following the procedure reported by DeFoort et al. [7], the following data were gathered:

a. Burning Rate (R_B). This is the average rate that the dry rice hull consume while bringing water to a full boil, or

$$R_B = \frac{F_{cd}}{t_c} \qquad (1)$$

where:
F_{cd} = amount of the dry rice hull consumed, kg
t_c = total time spent in bringing the water to full boil, hr

b. Thermal Efficiency. This is the measure of both the combustion efficiency of the carbonizer and the heat transfer efficiency to the pot. This parameter is calculated by dividing the amount of energy necessary to raise the water temperature of the pot from its initial to final value by the amount of energy that is available through ideal combustion of the rice hull used during the test, i.e.

$$\eta th = \frac{C_p * m_W * (T_f - T_i) + H_v * (m_{w\_i} - m_{w.f})}{(F_i - F_f)\left(1 - \frac{M}{100}\right) * LHV_{rh} - (F_i - F_f) * \frac{M}{100} * (C_p * (T_b - T_a) + H_v) - LHV_{crh} * C_c} \qquad (2)$$

where:
m_w = mass of the water, g
m_{wi} = initial mass of the water, g
m_{wf} = final mass of the water, g
c_p = specific heat of water, 4.186J/g – K
H_v = enthalpy of vaporization of water, 2260 J/g
T_a = ambient temperature, K
T_b = boiling temperature, K
T_f = final water temperature, K
T_i = initial water temperature, K
F_i = initial mass of the rice hull prior to test, g
F_f = final mass of the rice hull prior to test, g
M = moisture content of rice hull (%), wet basis
LHV_{rh} and LHV_{crh} = lower heating values of rice hull (14277 kJ/kg) and carbonized rice hull (12560 kJ/kg), respectively.

c. Overall firepower. This is a measure of the average rate of energy released from fuel combustion transferred to the pot and surroundings over the duration of the test,

$$FPo = \frac{LHV_{rh} * F_{cd}}{t_c} \qquad (3)$$

where:
LHV_{rh} = lower heating value of rice hull, kJ/kg
F_{cd} = amount of the dry rice hull consumed, kg
t_c = amount of time elapsed during the test, hr

d. Useful Power. The average rate of energy released from fuel combustion that is transferred to the pot over the duration of the test,

$$FP_u = \eta th * FPo \qquad (4)$$

where:

η_{th} = thermal efficiency, in decimal
FPo = overall firepower, kW

2. Oven test

This test was conducted to evaluate the potential uses of the oven by determining its performance in terms of utilizing the heat generated by the carbonizer. One way to evaluate its performance was to measure the temperature distribution inside the oven. The same set of instrument as in the boiling test was used in measuring the temperature. The temperature probes were placed at different locations inside the oven, i.e. top, middle, and bottom, to measure and record the temperature distribution inside. The temperature inside was taken every minute until there was no further increase in temperature readings. This was done at different settings of regulating valve (closed, ¼ open, ½ open, ¾ open, fully open).

Results and Discussion

Water boiling test

The water boiling performance parameters (boiling time, burning rate, overall power, useful power and the overall thermal efficiency) of the cooking attachment are shown in Table 1. The lowest boiling time was found when the regulating valve was fully-opened which took only 0.53 hours (31.8 min) to boil 30L of water. On the other hand, setting the regulating valve at ¾ open, ½ open and ¼ open, the average boiling time resulted to 1.12, 1.58, and 1.83 hours boiling time, respectively. This is evident that increasing the valve opening decreases the time required in boiling water since much heat is being delivered to the cooking chamber. The variations of these data with respect to temperature are shown in Figure 5.

The highest fuel burning rate was found to be 12.45 kg of dried rice hull per hour at fully-opened valve. This was almost twice when the regulating valve was set at ¼ opening (Table 1). The decrease in rice hull consumption could be the result of the lowered temperature at the carbonization zone (zone in rice hull bed where partial combustion takes place) since some of the heat were absorbed by the cooking attachment. However, higher yield of charcoal was achieved at low carbonization temperature [9].

The overall firepower is the output power of the heat-generated by the carbonizer. It indicates how much energy is released from the fuel combustion transferred to the cooking pot and the surroundings of the cooking attachment over the duration of the test. Average firepower of the generated heat varied from 26.66 – 27.98 kW in ¼ to ½ opened valve and 36.57 – 49.41 kW in ¾ to fully-opened valve, respectively.

The useful power is the fraction of the overall power that is eventually transferred to the cooking vessel for boiling water. The ratio of the useful power to the overall power indicates the fraction of overall firepower actually used for cooking. The larger the fraction, the larger will be the effective useful power [10]. The ratios of useful power to overall firepower were 0.20, 0.23, 0.27 and 0.30 for ¼, ½, ¾ open and fully-opened valve, respectively.

The overall thermal efficiency of the carbonizer when used as heat source ranges from 20% to 30%. Similar result was obtained by Mominur and Razia [10] using the *Nada Chulha* and *Sugam Chulha* biomass cooking stoves in India, which used rice straw as fuel in water boiling test. Moreover, the thermal efficiency also did not vary much from that of the Gyapa stove (27.3 % average thermal efficiency) and the Ahinbenso stove (28.3% thermal efficiency) in Ghana which made use of wood charcoal as fuel [11]. Thus, the performance of the carbonizer as heat source is already acceptable especially considering the fact that, in this case, the otherwise-wasted heat is just a secondary product, next to biochar.

The temperature profiles at different valve settings are shown in Figure 6. As shown, the larger is the opening of the regulating valve, the steeper is the temperature profile, an indication that more heat flows into the cooking attachment per unit time. As a result, the boiling time is also shortened.

Table 1. Water boiling performance at different settings of the regulating valve.

PERFORMANCE PARAMETER	Regulating valve setting			
	¼ open	½ open	¾ open	Fully - open
RH MC, % wet basis	6.15	6.15	6.15	6.15
Boiling time, hr	1.83	1.58	1.12	0.53
Burning Rate, kg/hr	6.72	7.06	9.22	12.45
Thermal efficiency, %	20.71	23.05	27.02	30.29
Overall power, kW	26.66	27.98	36.57	49.41
Useful power, kW	5.52	6.45	9.88	14.97
RH consumed, kg	20.53	19.06	18.02	12.00
CRH percent recovery, %	36.78	38.41	39.73	42.33

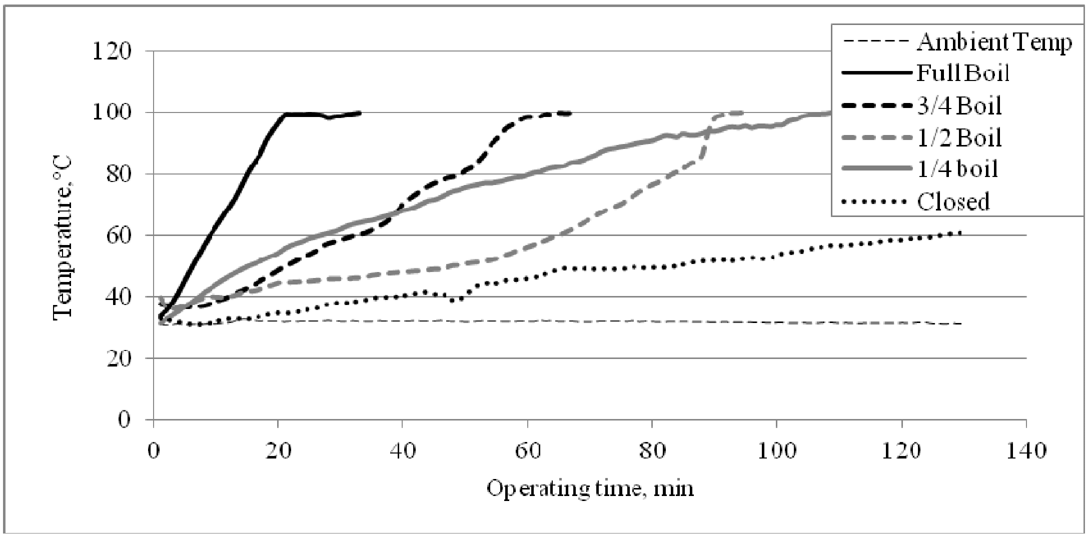

Figure 5. Temperature profile at the cooking attachment's heating chamber taken at different valve settings.

Oven Test

Effect of valve settings

The temperature distribution inside the oven compartment was determined every minute. Temperatures were separately gathered with respect to the location of the trays (top, middle and bottom). The temperature profile at different valve settings (full and half open) are summarized in Figure 7. As shown, the temperature did not vary much regardless of location inside the oven, an indication that more or less the temperature inside the oven is uniform. The highest temperature attained inside the oven were 250 °C and 60 °C at ~ 1.33 hours from the start of the test in full and half-opened valve, respectively. The top layer has a higher temperature than the bottom and middle layers.

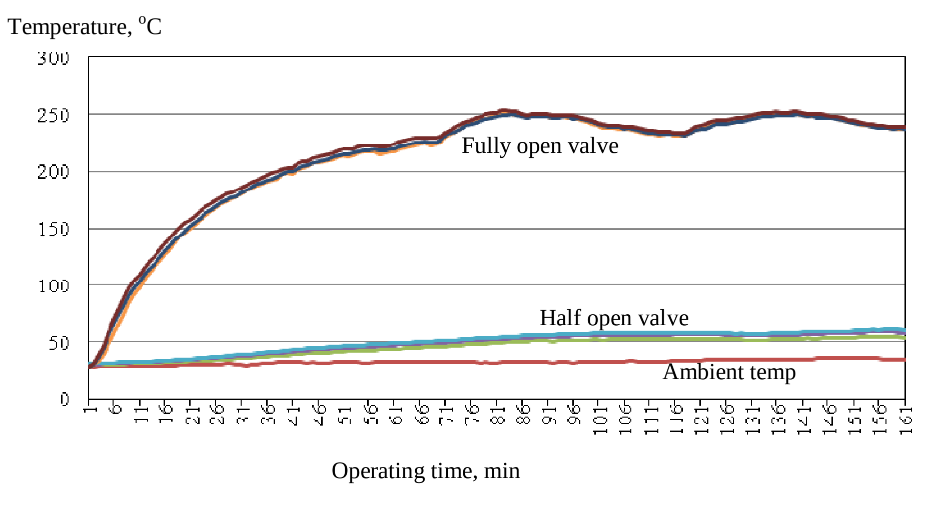

Figure 7. Temperature profile of inside the oven at two valve settings.

Controlling temperature

One important and desired feature of a heat recovery attachment is its capability to regulate the flow of hot gases passing through it so as to have some means of controlling the temperature. For the oven, the temperature inside the oven compartment is controlled by setting the inlet valve at different openings. Figure 8 shows the temperature profile inside the oven when this inlet valve was set alternately into fully-opened and closed position at a temperature range of approximately 170°C to 190° C. The temperature stabilizes and reaches 190° C in 45 min. From 190° C, the valve is closed and it takes 6 – 10 minutes for a temperature inside to lower down to 170° C same is true once the valve is opened and the temperature rises at 190°C. Results of the tests showed that it is very much possible that the oven temperature can be automatically controlled.

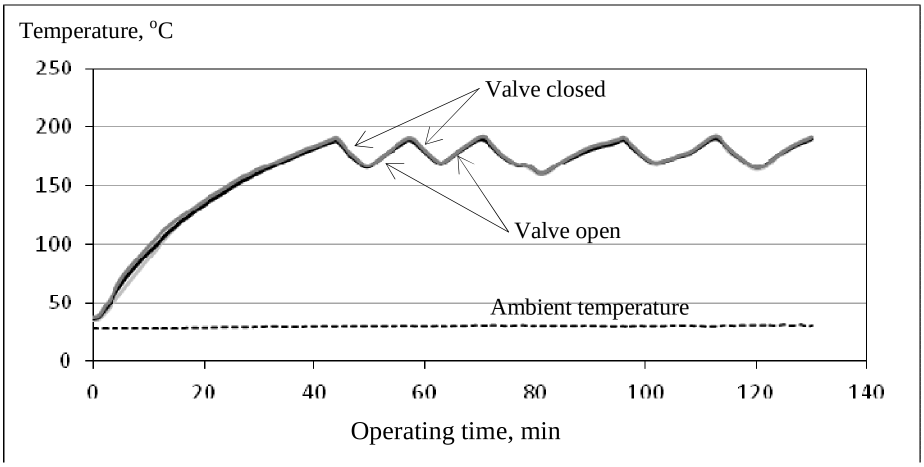

Figure 8. Effect of controlling the valve setting on the temperature profile.

Based on the performed evaluation of the temperature distribution inside the oven, it can be clearly seen that this oven has a lot of potential uses. Table 2 shows the possible uses of the oven.

Table 2. Baking Temperature and Time

Food Commodity	Temperature, °C	Time, min
Biscuits [1]	218 – 232	10 – 15
Cookies [1]	177 – 205	08 – 15
Cup cake [1]	177 – 190	15 – 25
Bibingka [2,3]	176 – 260	15 – 20
Pandesal [4]	176 – 180	08 – 20
Macarons [5]	176 – 180	15 – 20
Pizza[6]	200 – 250	10 – 15
Roasting whole chicken [7]		
3 – 5 lb boiler	176 – 180	75 – 90
6 – 8 lb roaster	176 – 180	90 – 150

Source:
[1]http://www.degraeve.com/reference/cake-baking-temperatures-time.php
[2] http://www.dipologcity.com/Dipolog Cooking2.htm
[3] http://www.manyamanmalinamnammabsiyummy.blogspot.com/2011/07/basic-bibingka-rice-cake-baking.html
[4] http://www.blog.junbelen.com/2010/03/24/how-to-make-pan-de-sal-filipino-bread-rolls-at-home/
[5] http://www.ctcoconut.com/sitebuilder/images/pdfs/coconutrecipes1.pdf
[6] http://www.allrecipes.com/howto/topping-and-baking-pizza
[7]http://www.fosterfarms.com/cooking/chicken/roasting_chicken.asp

Summary and Conclusion

A lot of studies show that diversifying famers' sources of income will enhance their resilience to climate change. This study evaluated the potential of the CtRH carbonizer as heat source for processing food products so that it could provide farmers opportunities for making additional sources of income. .

From the results of the tests conducted, the following conclusions could be drawn:

1. The heat generated by the carbonizer is sufficient to provide the heat requirements in cooking. Based from the water boiling test, the equivalent useful power available from the generated heat is close to 15kW;
2. The carbonizer performed well as heat source for the two fabricated heat recovery attachments, the cooking attachment and the oven. With the provision of a regulating valve which controls the amount of hot gas (products of combustion) flowing into each of these HRAs, it is possible that the temperature can be automatically controlled or regulated. This is important when cooking high value food products which require certain range of temperatures;
3. While supplying heat to process food products, the carbonizer produced rice hull biochar at a rate of 9.6 kg/h;
4. At fully opened valve setting, the highest temperature reading obtained at the inside of the oven was 250^{o}C, an indication that a lot of food products can be produced using the fabricated oven attachment.

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