COGENERATION OF BIOCHAR AND ENERGY FROM RICE HULL: TOWARDS SUSTAINABLE AGRICULTURE IN MARGINALIZED PHILIPPINE FARMS

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Abstract: This study seeks to integrate both energy and food security alongside pollution mitigation activities at farmers' level. In particular, it aims to utilize the heat generated during the production of rice hull (RH) biochar for pumping water. A small boiler and a jet pump were designed, fabricated, and retrofitted into the PhilRice-developed continuous-type RH carbonizer. The boiler was used to recover the heat from the exothermic carbonization process in converting water into steam. The generated steam was then used as the motive fluid of the jet pump for pumping water. A complete set up of the carbonizer-pump system was established to evaluate its technical feasibility. Performance test results showed that the system, equipped with a 5mm jet pump, was able to pump water from a pond (2.1m suction head) at a discharge rate of at least 15.5 liters/min, consuming 22.7 kg RH/h while producing biochar at 9.1 kg/h and a smokeless emission with CO content of 431 ppm. Higher discharge rates were observed at higher operating pressures. The minimum operating pressure by which the system could no longer pump water was 2.8 kg/cm^2.

Keywords: Biochar; Carbonization; Jet pump; Rice hull; Sustainable agriculture.

INTRODUCTION

The Philippines' Renewable Energy Act of 2008 and the Biofuel Act of 2006 have attracted renewed focus on sustainable and appropriate agricultural waste utilization for both energy and food security. Improving the productivity of the Philippine rice systems has been a fundamental national food security issue for some time. This work seeks to integrate both energy and food security alongside pollution mitigation activities.

At present, the conversion of rice hull or husk (RH) into biochar, popularly called carbonized rice hull or CRH, is becoming a popular practice among farmers particularly those practicing the *Palayamanan*®. *Palayamanan*® is an integrated system of farming practiced mostly in rainfed and other marginalized areas of the Philippines which highlights the purposive integration of various farming components such as rice and other crops, livestock, fish, and recycling so that nothing is wasted; everything in the farm is a precious resource. It also ensures food availability and increases farm productivity, profitability, and economic stability of farm families [1]. Under this system of farming, the CRH has a variety of uses, the most popular one is its being used as a soil conditioner and organic fertilizer ingredient.

It is also used as bedding or absorbent material to facilitate urine and manure collection in poultry, swine, and livestock. Once saturated, the CRH is collected and incorporated into the soil as organic fertilizer. The use of biochar is beneficial as it can aid in: (a) nutrient retention and cation exchange capacity, (b) decreasing soil acidity, (c) decreasing uptake of soil toxins, (d) improving soil structure, (e) improving nutrient use efficiency, (f) increasing water-holding capacity, and (g) decreasing release of non-CO_2 greenhouse gases such as CH_4 and N_2O [2]. Various reports [3, 4, 5, 6] also support these findings.

The development of the PhilRice continuous-type rice hull (CTRH) carbonizer with heat utilization capability [7] opens opportunities for using the heat generated during the carbonization process to some practical applications in the farm. This system of utilizing heat while producing biochar would help increase farmers' income and productivity in a highly sustainable way. It is also an indirect way of helping mitigate global warming. The practice of converting plant biomass into biochar is a simple form of carbon sequestration since some part of the carbon absorbed by the plant during its whole growing period has been removed from the cycle. In effect, the total amount of carbon released to the atmosphere is less than that being absorbed by the plant during the whole growth duration, thus making the practice carbon negative [8]. The 'carbon negativity' of this practice would be enhanced if the heat generated during the carbonization process would be utilized as an alternative source of energy in farming operations that traditionally use fossil fuels.

In the current practice of CRH production, the heat generated during the carbonization process is just wasted. This heat, being a form of energy, could be used to satisfy some basic needs within the farm. With a suitable complementary technology, it could be utilized for pumping water, among other possibilities. Water is a basic need of the farm such that combining the two operations (biochar production and water pumping) would be practical. In general, this study aimed to develop a system that combines biochar production with pumping water for irrigation, utilizing the heat generated from the RH carbonization process. Specifically, it aimed to:

1. design and fabricate a boiler (steam generator) for retrofitting into the existing CTRH carbonizer;

2. design and fabricate a jet pump as a component of the system that makes use of the generated steam as driving fluid to pump water;

3. To test and evaluate the performance of the system.

MATERIALS AND METHODS

Conceptual Framework

The partial combustion of biomass to produce charcoal is an exothermic process, i.e., it generates heat. The magnitude of the generated heat depends on the design of the carbonizer where the biomass-to-charcoal conversion process takes place. Theoretically, RH has a heat content of 13.24 to 16.20 MJ/kg [9] and a significant portion of it is just wasted during carbonization. With the necessary technological interventions, this generated heat can be used to convert water into steam and be used to drive a jet pump for pumping water for irrigation (Fig. 1). Thus, with RH as the input, the system generates two important products that enhance crop growth and yield (among other benefits) leading towards increased income and productivity of a farmer: (a) the CRH (biochar) is used as soil amendment, as main ingredient of organic fertilizer, or other related uses, and (b) the pumped water is used for irrigation or for other purposes within the farm.

System Components

To evaluate the technical feasibility of using the carbonization-generated heat for pumping water, a prototype of the RH carbonizer-pump system was set up using the following components:

RH carbonizer. The system used the PhilRice CTRH carbonizer (Fig. 2). In this carbonizer, the heat generated during the carbonization process is maximized since the gaseous products of partial combustion (mostly carbon monoxide, methane and hydrogen) are combusted before coming out of the chimney. This, in effect, resulted in a smokeless emission at the chimney [7].

Heat recovery component. To recover the heat generated during its operation, a small fire-tube type boiler, 14.8 cm in diameter and 25 cm in height was designed, fabricated, and retrofitted at the top of the carbonizer's combustion chamber. It is composed of 67 tubes serving as passageways for the hot gas from the combustion chamber to the chimney. The walls of boiler were fabricated from 3mm steel plate while the tubes were fabricated from 12.5mm black iron (BI) pipe schedule 80. The computed volume and the total surface area exposed to heat was 9.1 liters and 7,367 m^2, respectively. Two holes were provided along a vertical line at the side, one at the top and the other at the bottom portion, where the same 12.5mm BI pipes were fully welded in each hole for providing passageways for steam and feed water, respectively. Prior to its installation in the carbonizer, the boiler was tested at 10.5 kg/cm^2 pressure using a pneumatic compressor.

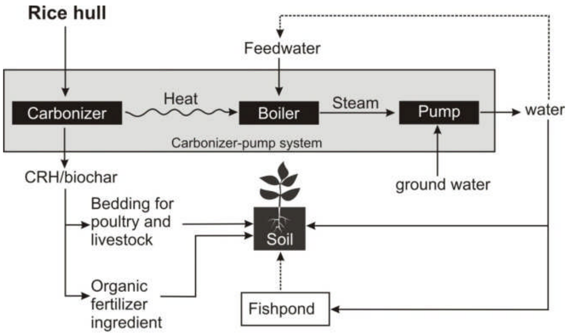

Figure 1. The Concept of Utilizing the Carbonization-generated Heat for Pumping Water within the Context of an Integrated Farming System.

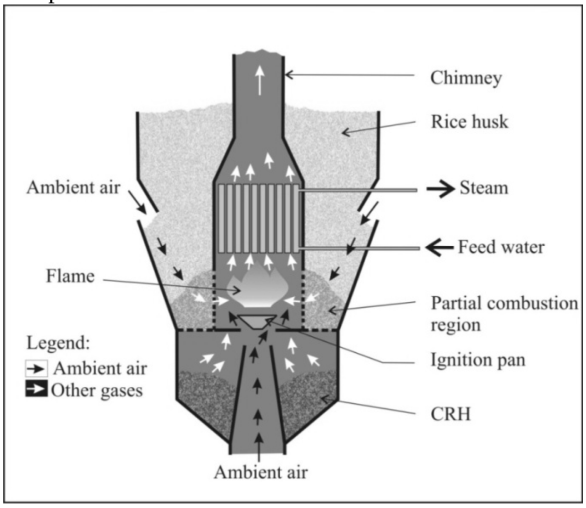

Figure 3. The System's Heat Source and Its Heat Recovery Component.

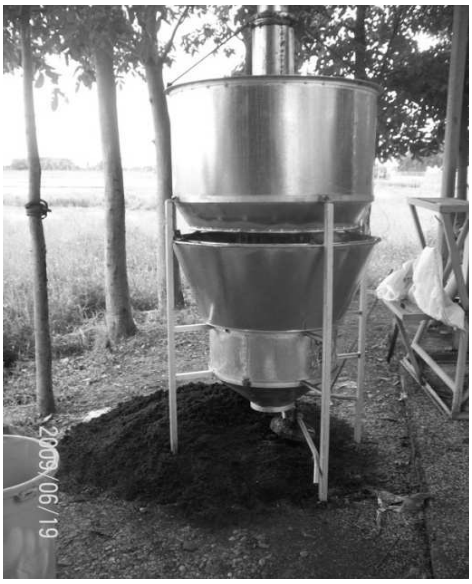

Figure 2. The PhilRice CTRH Carbonizer.

Figure 4. The Existing RH Carbonizer Commonly Used by the Farmers.

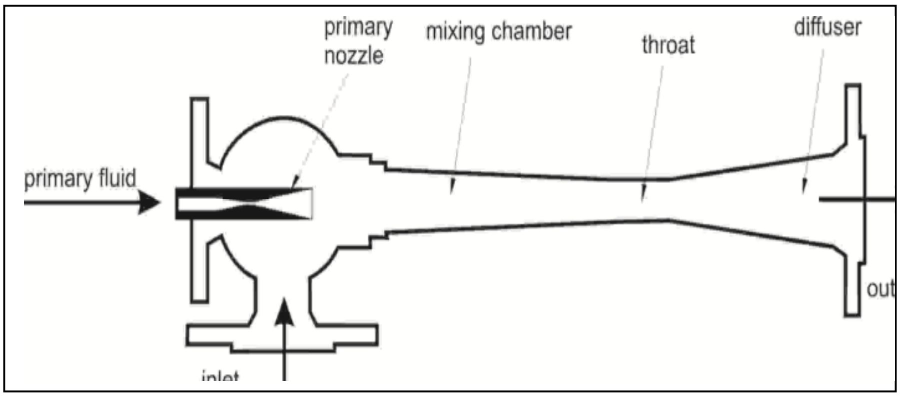

Figure 5. Schematic Diagram of a Jet Pump

Water pump. A jet pump was designed and fabricated for use as the system's water pumping component. Also called as ejector [10], a jet pump is known for its simplicity in design as it has no moving parts. It was fabricated mostly from commercially available galvanized iron (GI) pipes and fittings. The pressurized steam generated by the boiler serves as its driving fluid and creates negative pressure that causes the water from a lower level to be pumped out to a higher level.

Other accessories. A manually operated laboratory piston pump was used for refilling the boiler with water for continuous operation of the system. A commercially available pressure relief valve (with release pressure of 10.5 kg/cm^2) was installed as a safety device along the steam line connecting the boiler to the jet pump. Flow restricting valves (steam cut off valve, foot valve, etc.) were likewise installed along designated points in the system's water and steam pipe lines.

Performance evaluation

A complete setup of the system was established beside a small pond that served as the source for pumping water. The total suction head was 2.1m. The following parameters were gathered to evaluate the performance of the system:

Boiler performance. The boiler, as a heat recovery device, was evaluated in terms of the following basic performance parameters:

a. Steam generation rate (Q). The amount of steam generated per unit of time was determined by allowing the boiler-equipped carbonizer to operate (at one load of the boiler) and then determine the time spent in converting all the water inside the boiler into steam, or

$$Q = \frac{W}{t} \qquad (1)$$

Where:

W = amount of water placed inside the boiler, kg

t = total boiling time, i.e. time from start of boiling up to the last appearance of steam.

b. Boiler efficiency (η). Boiler efficiency is defined as the fraction of the total heat released that is transferred to the water and steam. It is computed by dividing the enthalpy in the produced steam produced by the potential energy in the corresponding amount of fuel fired [11], or

$$\eta = \frac{Q \text{ x } (H-h) \text{ x } 100}{q \text{ x } HV} \qquad (2)$$

Where:

Q = Quantity of steam generated, kg/h

H = Enthalpy of steam, kJ/kg

h = Enthalpy of feed water, kJ/kg

q = Quantity of RH used, kg/h

HV = Gross heating value of the RH, kg/h

The equation assumes a complete combustion process where the fuel is all converted into ash which no longer has a heating value. In this study however, RH is converted into CRH which still has a heating value. Hence, Eq. 2 was modified as follows,

$$\eta = \frac{Q * (H-h) * 100}{q * (HV1-(HV2*Y))} \qquad (3)$$

Where:

HV1 = Gross heating value of the RH, kg/h

HV2 = Gross heating value of the CRH, kg/h

Y = CRH yield, decimal

Minimum operating pressure (MOP). In this study, MOP is defined as the pressure below which the system, under a particular set of operating conditions, is no longer capable of pumping water. This was determined by closing the steam cut-off valve, while the pressure at the boiler was building up, and opening it once the pressure was more than enough to pump water. While operating, this pressure subsided. The pressure at which water pumping stopped was then noted.

Water discharge. The system's capability to pump water was evaluated at specified range of steam pressure. This was measured using a container of known volume and a stop watch. For purposes of comparison, two nozzle sizes of the jet pump were tried.

RH consumption (Rh). The amount of RH consumed by the carbonizer, either as a stand-alone equipment (used merely in producing CRH) or as a component of the system, was determined.

Specific fuel consumption (F). This was measured using the following formula:

$$F = Rh/Wd \qquad (4)$$

Where:

Rh = amount of RH consumed (or carbonized) per unit time, kg/h

Wd = Water discharge, L/h

RESULTS AND DISCUSSION

System operation

The heart of the system is the CTRH carbonizer where the conversion of RH into biochar takes place. The RH is fed into the carbonizer's hopper and the bottom portion of the RH bed is ignited by a flame from a combusted kerosene placed in the carbonizer's ignition pan (Fig. 3). Partial combustion takes place at the ignited region of the RH bed in the immediate vicinity of the combustion chamber as limited amount of air enters into this region through the side opening, passing through the porous RH bed. The carbon in the RH reacts with the oxygen in the air to produce carbon monoxide (CO). Other chemical reactions take place in a similar manner as that of gasification [12] resulting in the production of other combustible gases such as hydrogen gas (H_2) and methane (CH_4). These combustible gases enter into the combustion chamber where they are combusted as ambient air, entering through the bottom opening of the carbonizer, mixes with them. In effect, heat generation is maximized and the resulting emission is much cleaner as compared to the conventional RH carbonizer that is commonly used by the farmers (Fig. 4). The products of complete combustion, which are hot gases then enter into the boiler tubes as they exit through the chimney. As a result, heat is transferred into the surfaces of the boiler, which heats up and converts the water inside into steam. Pressure is generated inside the boiler causing the steam to flow through the pipe lines into the jet pump's nozzle at high velocity. The jet pump (Fig. 5) uses the Venturi effect of its converging-diverging nozzle to convert the pressure energy of the steam, which serves as the motive (primary) fluid, to velocity energy and create a low pressure zone that draws in and entrains water [13].

System performance

The carbonizer can accommodate 40 kg of RH at full hopper capacity and can be ignited in 2-3 minutes. Steam generation started 3 to 4 minutes after ignition, accompanied by a hissing sound generated as steam came out from the nozzle of the jet pump. Beyond the minimum operating pressure, the system was able to pump water without difficulty of priming, utilizing only the heat generated during the carbonization process (Fig. 6). This system can replace the engine-driven irrigation pumps with the added benefits of biochar as by-product of operation.

From the series of test runs, the minimum operating pressure varies with the suction head and the jet pump's nozzle opening, among other parameters. The pumped water, being driven by steam, was 13-15^oC higher in temperature than the source. Figure 7 shows a typical steam pressure profile of the system for the two nozzle sizes of the jet pump, starting at the moment the steam valve was opened upon reaching a pressure of 7 kg/cm^2. Feed water had to be pumped to the boiler every 25 to 30 minutes, using part of the discharged water from the jet pump (with temperatures of 39 to 40^oC).

Boiler performance. When subjected to an actual steam pressure of 10.5 kg/cm^2 during laboratory tests (Fig. 8), the boiler was able to overcome failure, leaving no signs of metal deformations nor cracks. During the conduct of the performance tests, however, the system was only operated at a maximum pressure of 7 kg/cm^2 for safety reasons. At 4 kg/cm^2 pressure and 5mm nozzle opening, the 8 li water at the boiler was all converted into steam in an average of 20 minutes, or a steam generation rate of 24 kg/h. At this condition, and using other data presented in Appendix Table 1, the boiler efficiency was computed at 29.3%. The system's boiler efficiency is much lower compared to most industrial boilers which have efficiencies of the order of 90% [14]. However, considering that it just made use of otherwise-wasted heat and made of cheaper materials that are not excellent conductors of heat, the trade off may be worth.

Water discharge. Figure 9 shows the system's water pumping performance at a suction head of 2.1 m as affected by the generated steam pressure and the size of jet pump's nozzle. The graph also shows the minimum operating pressures (marked by vertical broken lines) which were 2.8 and 3.9 kg/cm^2 for the 5 mm and 3 mm jet pump nozzles, respectively. The graph suggests that higher discharge rates could be attained at higher steam pressures although a certain limit may be attained, as in the case of the 5 mm nozzle, beyond which no further increase in water discharge was observed. Of the two nozzle sizes, the 5 mm seemed to be a better choice since it requires a lower minimum operating pressure as well as higher water discharge for a particular operating pressure.

Figure 6. The RH Carbonizer-Pump System in Operation Showing a Close up of the Jet Pump (right).

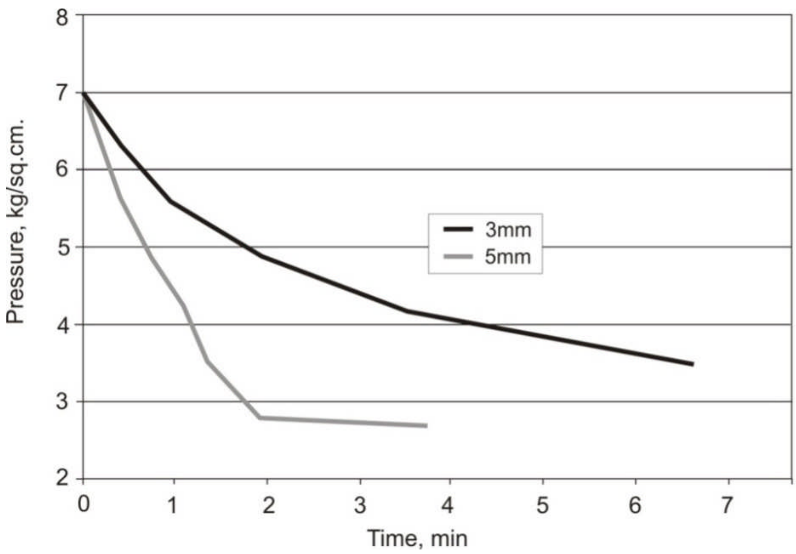

Figure 7. Pressure Profile of the System for the Two Nozzle Sizes Used for the Jet Pump.

Figure 8. The Generated Steam During Laboratory Testing of the Boiler.

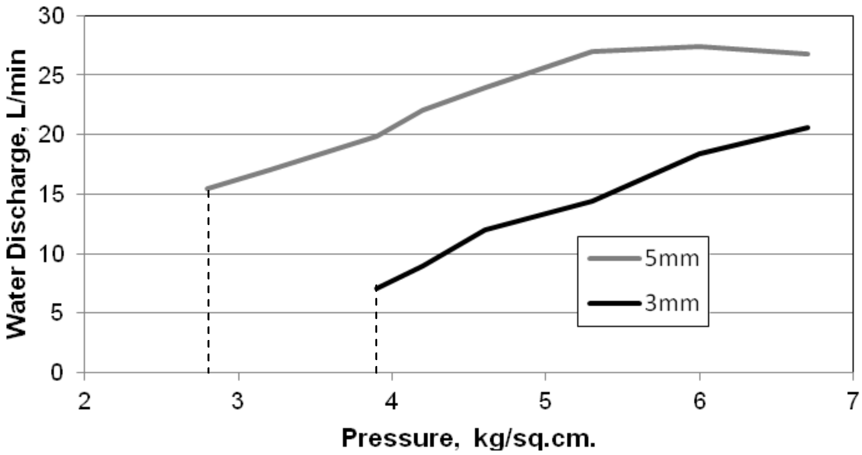

Figure 9. Water discharge as affected by nozzle size and steam pressure.

Table 1. System Performance at Two Modes of Operation.

PARAMETER	AS CARBONIZER ONLY	AS CARBONIZER-PUMP SYSTEM
Amount of RH consumed, kg/h	40.12	22.7
Amount of biochar produced, kg/h	14.4	9.1
Volume of water pumped, l/min	-	15.5
Specific fuel consumption, kg RH per m^3 water	-	25.2
Volume of water pumped per kg RH used, liters	-	39.7

Specific fuel consumption. For an operating pressure range of 2.8 to 7 kg/cm^2, the system consumed an average of 22.7 kg of RH per hour (Table 1) and pumped water at an average rate of 15.5 l/min (930 l/h) while generating biochar at 9.1 kg/h. However, when operated purely as a carbonizer, it consumed an average of 40.12 kg RH per hour. The decrease in the fuel consumption when the carbonizer was operated as a component of the system could be the result of the lowered temperature at the carbonization zone (zone in the RH bed where partial combustion takes place) since some of the generated heat were absorbed by the boiler. Worasuwannarak et al. [15] noted that higher yield of charcoal could be achieved at low carbonization temperatures.

Opportunities and Challenges. This technology can be a two-edged sword to fight climate change, i.e. increasing food production or enhancing food and energy security at the farmers' level (adaptation) while simultaneously helping reduce greenhouse gas emissions (mitigation) through biochar application in the soil as a form of carbon sequestration. It may also qualify as an answer to one of the "top 100 questions of importance to the future of global agriculture" [16]. To maximize the area to be covered by water for irrigation, the system can be complemented with a drip irrigation method wherein the water that is co-produced during the production of biochar can be stored in an elevated tank. Operating a system having a pressurized vessel of steam may expose the farmers, being the target users of this technology, to potential occupational hazards. However, this can be addressed through proper training of the farmers on the systems operation and maintenance procedures. On the other hand, further design improvements and optimization tests may be carried out to further lower down the system MOP while at the same time maximizing the water discharge.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated that water can successfully be pumped using the carbonizer-generated heat. Thus, RH carbonization to produce biochar for soil amendment or nutrient recycling can simultaneously be done with pumping water for irrigating crops or for other applications.

The system pumps water at a minimum discharge rate of 15.5L/min while producing biochar at a rate of 9.1 kg/h. It works best using the 5 mm jet pump nozzle where the minimum operating pressure was 2.8 kg/cm^2. Higher water discharge rates were obtained at higher operating pressures.

Results of tests, however, showed some major challenges that need to be overcome prior to the introduction of the technology to the farmers. Among these are (a) maximizing water discharge while minimizing the MOP to make the system much safer to operate, and (b) matching the capacity of the pump in relation to the size of the boiler.

ACKNOWLEDGEMENT

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Appendix

Table 1. Data used in boiler efficiency calculations.

PARAMETER	VALUE
Carbonizer data	
Quantity of RH consumed, kg/h	22.7
CRH recovery, %	39.8
Heat output data	
Quantity of steam generated, kg/h	24
Steam pressure, kg/cm^2	4
Enthalpy of steam at 4 kg/cm^2 pressure, kJ/kg	2739
Feed water temperature, ^{o}C	40
Enthalpy of feed water, kJ/kg	167.5
Heat input data	
Gross heating value of RH, kJ/kg	14,277
Gross heating value of CRH, kJ/kg	12,560
Boiler efficiency, %	29.3