DESIGN IMPROVEMENT OF THE PHILRICE CONTINUOUS-TYPE RICE HULL CARBONIZER FOR BIOCHAR PRODUCTION TOWARDS SUSTAINABLE AGRICULTURE

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Abstract: The use of biochar from rice hull (carbonized rice hull) is becoming popular among Filipino rice farmers particularly those practicing an integrated system of farming locally called as *Palayamanan*. Under this system of farming, carbonized rice hull is widely used as soil conditioner or as main ingredient in the production of organic fertilizers. Some farmers are also using it as animal bedding to absorb urine and fresh manure. The saturated biochar are then incorporated into the soil as organic fertilizer for vegetables and other crops. With this practice, farmers not only were able to save on fertilizer but also reduce their carbon footprints thus contributing to the global effort of reducing the greenhouse gas in the atmosphere. While the PhilRice-developed continuous-type rice hull carbonizer has been successfully used in the production of biochar for various uses in the farm, there were some weak points and operational concerns that were revealed only after its continued use. The major one is when operating during windy conditions wherein there were significant dusts and smoke emissions generated which exposed the operator to health hazards. Hence, the design was further improved. To further enhance the usefulness of the equipment, design improvements were also geared towards making it able to process biochar from other agricultural wastes that are commonly generated in the farm. Moreover, design refinements were also done on reducing its material and manufacturing requirements in preparation for its possible commercialization. The resulting improved prototype is flat sided which make it simpler to fabricate, incurring less material wastage, than the previous one. The flat sides makes use of 2mm thick metal sheets and their dimensions (0.8m x 1.2m) were chosen in such a way that no waste cuts are left from the two sheets (standard size: 1.2m x 2.4m) used. Unlike in the previous prototype where a side opening was provided to facilitate manual agitation of the rice hull bed, the improved prototype features a fully enclosed hopper. In terms of the cost of fabrication materials used the improved prototype costs 28.8% lower than its predecessor. Test runs conducted showed that the improved prototype can operate under windy conditions with no significant effect on emission. In most cases (at least 85% of the time), the prototype operates with clear emission at the chimney. Input capacity ranged from 20.6 to 36.2 kg/h with biochar recovery of 37.3 to 40.5% (by volume), depending on the condition of the rice hull and the frequency of collecting the processed biochar, among other factors. The prototype has been tested with and found to be able to process other agricultural wastes such as rice straw, small branches of trees, and coconut husk into biochar.

Keywords: Biochar; Biomass; Carbonized Rice Hull; Rice Hull; Rice Hull Carbonizer

INTRODUCTION

Rice hull or husk is the outer covering of the rice grain which is removed during the process of milling. It constitutes 20 to 25% of the rice grain [1] that is harvested from the field making it one of the most abundant agricultural residues of the country.

As long as rice remains to be the staple food of the Filipinos, rice hull, being the by-product of milling, will be continuously produced in the country. In 2011, an estimated amount of 3.7 million metric tons of rice hull was generated based on the *palay* production data of the Bureau of Agricultural Statistics. At a heating value of 14 GJ/ton [1, 2], this is equivalent to around 52 million GJ of energy or equivalent to 8.7 million barrels of oil. The energy obtained from agricultural residues like rice hull is a form of renewable energy and, in principle, utilizing this energy does not add carbon dioxide (a greenhouse gas) to the atmospheric environment, in contrast to fossil fuels [3]. If not properly utilized, however, rice hull will create growing problems of space and pollution in the environment [4].

The continuous pressure of producing more and more rice to feed the country's increasing population, coupled with the development and introduction of high yielding rice varieties and other yield-enhancing technologies, signals an increase in the amount of rice hull generated annually. Thus, it may worsen the disposal problem that most rice millers already experience. Aside from generating dust which causes respiratory problems and skin irritation, rice hull that are dumped in open fields and left to decompose generate methane which is a more potent greenhouse gas than carbon dioxide. Hence, finding ways that would help increase the use and value of rice hull is beneficial not only in terms of providing additional income opportunities for farmers but also in protecting our environment.

The conversion of rice hull into charcoal, commonly known as carbonized rice hull or CRH, is becoming a popular practice among farmers particularly those practicing the *Palayamanan*® system of farming. *Palayamanan*® is an integrated system of farming similar to the *bahay-kubo* concept 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 [5]. It is also being considered as a local rice research and development strategy [6] where the development of location and farmer-specific technologies are being based. Under the *Palayamanan*®, the CRH has a variety of uses, the most popular of which is its being used as a soil conditioner. It is also used as bedding or absorbent material to facilitate urine and manure collection in poultry, swine and livestock. Once saturated, it is collected and applied to the soil as organic fertilizer.

Carbonization of biomass has a number of advantages when compared with any common biological treatment such as composting [7]. It generally takes only hours, instead of the days or months required for biological processes, permitting more compact reactor design. In addition, some feedstocks are toxic and cannot be converted biochemically. The high process temperatures can destroy pathogens and potentially organic contaminants [8, 9]. Furthermore, useful liquid, gaseous and solid end-products can be producedfrom carbonization [10], and at the same time contribute to odor reduction [11] and additional socio-economic benefits.

As reported by the Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency, the use of biochar is beneficial as it can aid in: (1) nutrient retention and cation exchange capacity, (2) decreasing soil acidity, (3) decreased uptake of soil toxins, (4) improving soil structure, (5) nutrient use efficiency, (6) water-holding capacity, and (7) decreased release of non-CO_2 greenhouse gases such as CH_4 and N_2O. Some authors complement these findings [12, 13, 14, 15]. For CRH in particular, the Philippine Rural Reconstruction Movement (PRRM) came up with the following findings: (1) it is rich in nutrients like phosphorous, potassium, calcium, and magnesium which are essential in rice plant growth; (2) its bulky and porous characteristics enable it to store water and facilitate air circulation thereby controlling soil temperature; and (3) because it is a clean biomass and pathogen-free, it is a conducive living space for beneficial soil micro-organisms [16]. CRH is also used as base material for making microbial inoculants used in composting [17].

Carbonization is simply the process of converting a biomass (carbon-containing substance such as rice hull, wood, etc.) into carbon or carbon residue. This process requires the application of heat on the biomass or allowing it to undergo partial combustion so that the volatile matter and other substances in it would be removed. Initially, the biomass remains slightly above 100^{o}C until it is bone dry. When the free moisture evaporates, the temperature rises and at ~270^{o}C, the biomass begins to decompose emitting gases composed mainly of CO, CO_2, acetic acid, and methanol. At this point, the reactions are still endothermic. Between 290 and 400^{o}C the breakdown continues to produce a mixture of non-condensable gas, combustible gas, and condensable gases that form a complex liquid called pyrolysis oil [18].

Several biomass carbonizers already exist in the market. Although these carbonizers vary in their capacities and physical structures, their operating principles can be classified under two basic categories, namely, (a) those that operate by partial combustion (direct carbonization) and (b) those that operate by pyrolysis (indirect carbonization). There are cases, however, that these two operating principles could be found in one particular design of a carbonizer.

In carbonizers operating by partial combustion, the material to be carbonized provides the energy required for carbonization. Control is exercised over the entry of air during the process so that the load does not merely burn away to ashes, as in a conventional fire, but decomposes chemically to form charcoal [19]. There is no medium that separates the load from the region that undergoes partial combustion. In this method, all condensable products as well as gases are usually not recovered. The rice hull carbonizer that the Filipino farmers currently use (commonly referred to as the *open-type* carbonizer) falls under this category. It is composed of two parts, namely the central cylinder and the chimney. The central cylinder is made up of a galvanized iron sheet with 3-cm diameter holes drilled on its side. A cover with a 10-cm hole at its center is provided and welded on the top lid while its base is left open. Mounted on the hole of the top cover is the 10-cm dia. x 120-cm long chimney where the flue gas escapes during its operation. To operate this carbonizer, fire is started inside the central cylinder using crumpled papers and piled small pieces of wood. Once the pile of wood is burning and the fire has stabilized, raw rice hulls are placed around the central cylinder. The fire inside the central cylinder will gradually burn the rice hulls that are in contact with its sides. More rice hulls are then placed all around and way above the central cylinder. The products of combustion, being lighter than the ambient air, move upward and escape out of the chimney. This movement creates a negative pressure inside the central cylinder such that fresh air is sucked and forced to enter into the rice hull bed, passing through the region where partial combustion is taking place. Because of this, the supply of air for the partial combustion process is sustained. The region of partial combustion then moves towards the surface of the rice hull bed. When this region reaches the surface of the bed, as manifested by the presence of several dark spots, the whole batch of rice hull is thoroughly mixed so as to carbonize those patches with unburned rice hull. Water is then sprinkled to stop the burning so that the burnt rice hull will not turn into ash. This carbonizer could process 1.6 m^3 of rice hull into CRH in four to five hours at a carbonization temperature range of 520^{o}C to 560^{o}C [5]. It has no provision for heat recovery. One of its drawbacks is the excessive smoke (where the operator is exposed to) especially at the final stage of its operation wherein the remaining unburned rice hull have to be mixed with those that are already charred.

Pyrolysis is generally described as the thermal decomposition of the organic components in biomass waste, in the absence of oxygen, at mediate temperature [20]. This makes pyrolysis an endothermic process. Because of this, carbonizers that operate by pyrolysis require the application of an outside source of heat. The material being carbonized is usually contained in a closed chamber and separated from the source of heat although the heat may come from the combustion of the same material being carbonized. The hot gases coming from this external heat source may come into either direct or indirect contact with the load. Most of the carbonizers available in the market fall under this category. These carbonizers are foreign-made and the cost of acquiring them is undoubtedly prohibitive. Among these, as reported by Dutta [21], are the following given below.

Pillard Rotary Carbonizer

It consists of an inclined rotary furnace where a part of the pyrolytic gas is recycled and burned to provide heat necessary for carbonization. The hot flue gases come in direct contact with the raw material (load) slowly moving down the inclined furnace. Thus, the raw materials are carbonized in the process.

Thompson Converter

This is considered as one of the oldest indirectly heated screw-fed carbonizer. It consists of a number of metal tubes heated externally. The raw material is conveyed through the heated tubes by means of screws and gets carbonized in the process. The volatile gases are fed back into the burner so that the whole operation becomes self-sustained.

Keil-Pfaulder Converter

This is normally used for batch carbonization of waste wood with cycle time of 6-8 hours. The blower extracts volatile products from the bottom of the converter. Condensation separates the tar from the gas after which the gas is burned to provide heat for carbonization.

In 2010, PhilRice developed a rice hull carbonizer that operates in a continuous mode with almost smokeless emission [22]. Although the prototype had already been operating acceptably, concerns emerged after its prolonged use which required further refinements on the design of the equipment. This study was conducted to further improve/refine the design of this carbonizer prior to its commercialization.

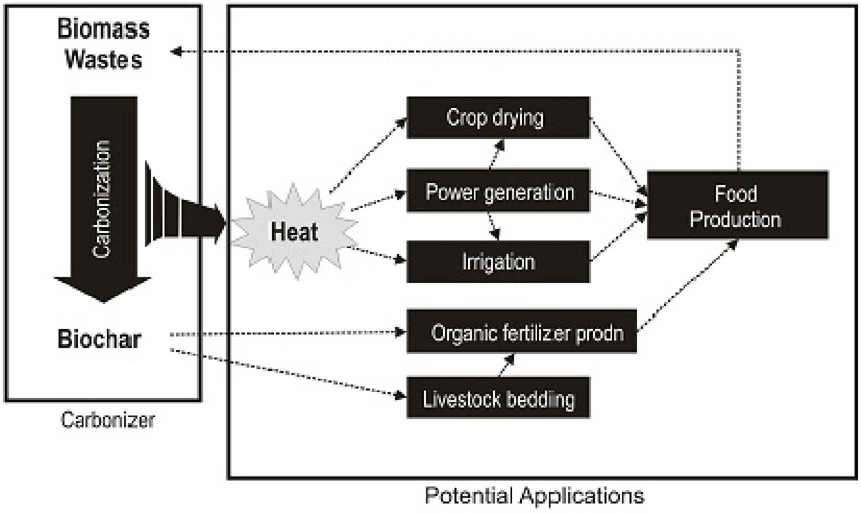

Figure 1: The developed carbonizer in relation to various potential applications in the farm.

Figure 2: The prototype of the continuous rice hull carbonizer prior to design improvements

Figure 3: The improved prototype of the continuous rice hull carbonizer.

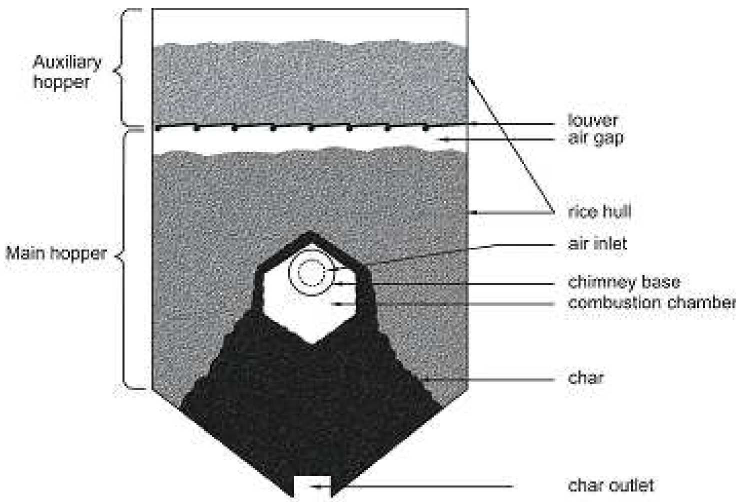

Figure 4: Schematic drawing of the improved prototype.

MATERIALS AND METHODS

Conceptual framework

In general, the development of the carbonizer opens an opportunity towards the development of a biomass carbonization-based engineering technologies that the farmers could use to help increase their income and productivity while helping protect the environment. With the development of appropriate complementary technology, the heat generated during the carbonization process could be also used for some direct or indirect applications in the farm (Fig. 1). Thus, undoubtedly, this practice will help enhance farmers' income and productivity in a highly sustainable manner. Moreover, it also helps address issues on climate change as the use of the produced charcoal as biochar may contribute to climate change mitigation and soil amelioration [23].

Design improvement and prototype fabrication

The improvement of the prototype carbonizer (Fig. 2) was done primarily to address the following concerns: (1) Improving performance during windy conditions. When operated during windy days (prevailing winds of approximately 10m/s or higher), the following were observed: (a) exposed rice hulls at the side opening of the carbonizer, particularly at the upstream side (facing the wind direction), are blown off which exposes the operator to dusts and make it difficult to operate; (b) The progress of the carbonized zone in the rice hull bed is not uniform - the portion at the upstream side carbonized faster than that those at the downstream side; (c) Open flame easily gets developed at the upstream side of the side opening. This makes operating the machine during windy days quite dangerous. (2) Ignition and re-ignition of the combustion chamber. Firing of the combustion chamber must be done while the hopper is still half-filled since access to the ignition chamber is already difficult when it is already full. There were instances however that, while the equipment was already in operation, the flame was extinguished due to the disturbance of the rice hull bed during agitation. In conditions like these, the carbonizer normally emits thick smoke at the chimney; (3) Enhancing the equipment's capability to process other biomass since rice hull is getting scarce in some areas due to its increasing demand. Besides, agricultural wastes are more readily available in the farm than rice hull. (4) Enhancing the capability of the carbonizer to recover the heat for other practical applications.

A new and modified design of the carbonizer was developed making use of value analysis [24]. In spite of the magnitude of the revisions made on the overall design of the machine, the same operating concept was however still used. The main goal was to overcome/satisfy the various aforementioned concerns. The fabrication process was monitored from time to time to ensure that the specifications were followed and to validate if the components were easy to fabricate as what was being desired.

Prototype testing

The performance of the improved prototype was first tested using rice hull after which other agricultural wastes such as rice straw, coconut husk, and wood (small branches of trees) followed. These materials were sundried to lower down moisture content to at most 10%. The final MC of the material was taken using oven-dry method following standard operating procedure. During testing, the prototype was operated for at least an hour while getting the following data.

Machine capacity (C)

This is the amount of material that is carbonized by the prototype carbonizer per unit time, computed as follows,

$$C = W_t / T$$

Where:

W_t = total weight of material loaded into the carbonizer

T = total time of operation

Charcoal yield (Y)

The following formula was used which was patterned from Sugumaran and Seshadri [25],

$$R = 100 \times (W_c / W_t)$$

Where:

W_c = total weight of charcoal produced (output).

W_t = Initial weight of the raw material (input)

Amount of ignition fuel used in firing the carbonizer

Biodiesel was used to start the firing of the carbonizer at its combustion chamber. The fuel was sprinkled using an improvised atomizer to evenly distribute the fuel on the exposed surfaces of the material to be carbonized at the combustion chamber.

Ignition time

This was the time taken from the moment fire is introduced into the combustion chamber up to the moment a vigorous flame is established and opening that gives access to the combustion chamber is closed.

Table 1: Results of series of test runs of the improved prototype using rice hull.

PARAMETER	TEST RUN			
	1	2*	3**	4
Date conducted	6 Sep ‘11	19 Dec ‘11	23 Feb ‘12	2 Mar ‘12
Capacity, kg/h	26.2	24.4	24.2	22.0
Charcoal Yield,% w.b.	42.1	36.8	36.2	35.45
Ignition time, min	2	1.6	1.8	1.42
Amt of diesel used firing, mL	50	50	-	21
Loading/reloading time, % of total	3.1	4	-	1.2
Char collection time, % of total	2.6	2.1	-	1.0
Agitating time, % of total	3.2	3.8		2.0
MC, %	-	-	-	6.32

* Ave. wind speed of 11.2 kph; max. reading of 32.04 kph
** Ave. wind speed of 10.8 kph; max. reading of 25.92 kph

Table 2: Performance of the improved prototype using biomass other than rice hull

Date conducted	RICE STRAW	COCO HUSK	WOOD
Capacity, kg/h	12.00	20.0	32.18
Charcoal Yield,% w.b.	23.89	17.96	23.98
Ignition time, min	0.87	1.42	2.63
Amt of diesel used in firing, mL	37 ml	40 ml	113 ml
Loading/reloading time, % of total	5.6	2.2	2.0
Char collection time, % of total	5.6	5.3	1.9
Agitating time, % of total	0	0	0
MC, %	8.15	10.47	6.53

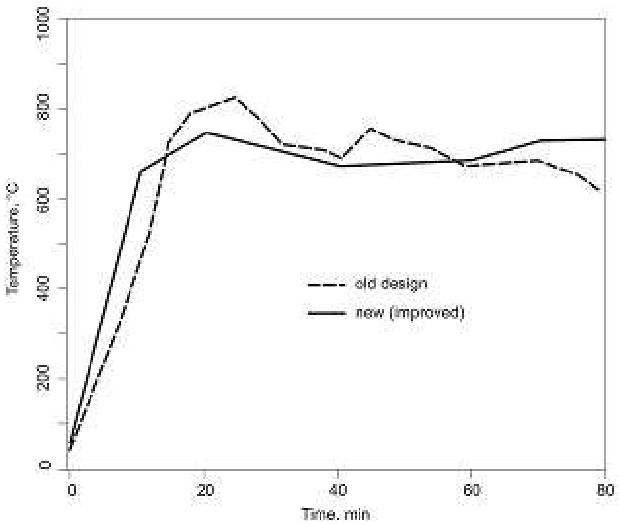

Figure 5: Temperature at the combustion chamber of the improved prototype as compared to the previous one.

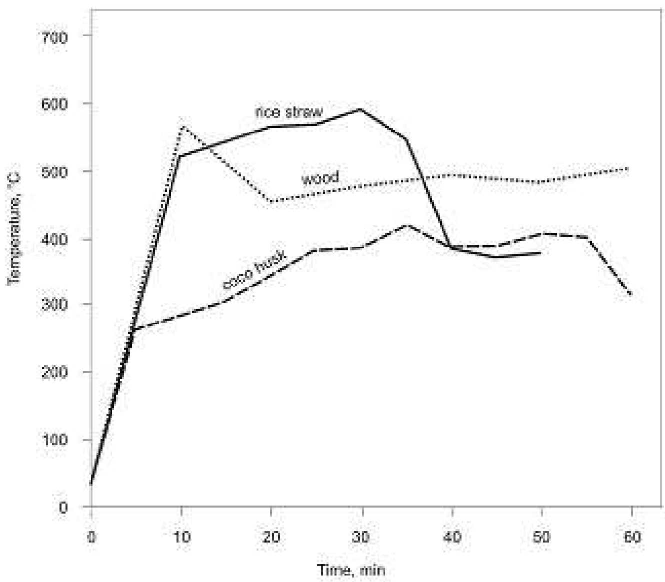

Figure 6: Temperature readings at the combustion chamber during the carbonization of wood, rice straw and coconut husk.

Total time of operation (T)

This covers the time from the start of firing the carbonizer up to the time it is emptied from carbonized material. This includes the following operational activities whose time requirement were also separately monitored: (a) loading/reloading of hopper, (b) collecting the charcoal, and (c) agitating/stirring the hopper contents.

Temperature

To have an estimate of the temperature at the combustion zone, a temperature probe was installed along the burner tube. The probe was connected to a temperature recorder using K type thermocouple wires. Temperature was taken every after 10 minutes while the carbonizer was operating.

RESULTS AND DISCUSSIONS

The improved prototype

Figure 3 shows the resulting prototype after making some design improvements and modifications. As shown, the new prototype is flat sided which make it simpler to fabricate, incurring less material wastage, than the previous one. The flat sides makes use of 2mm thick BI metal sheets and their dimensions (0.8m x 1.2m) were chosen in such a way that no waste cuts are left from the two sheets (standard size: 1.2m x 2.4m) used. Unlike in the previous prototype where a side opening was provided to facilitate manual agitation of the rice hull bed, the improved prototype features a fully enclosed hopper to make it able to operate during windy conditions. In terms of the cost of fabrication materials used, assuming that the same kind of materials are used for the sidings and for the chimney, the new prototype costs 28.8% lower than its predecessor (Appendix Tables 1 and 2).

Figure 4 is a schematic diagram of the improved prototype showing the major working parts. The top portion of the hopper is provided with louver-type cover which separates the hopper into two, the auxiliary hopper (top portion) and the main hopper (bottom portion). The main 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 main hopper is filled with the material to be carbonized. This empty space serves as the combustion chamber since it is where combustion takes place as the ambient air, passing through the holes of the burner, mixes with the pyrolytic gases and those that are products of incomplete combustion. It is also where the material to be carbonized is initially ignited during start of the operation. The inverted V partition is designed to be easily detached to facilitate repair or replacement since it is the one that has the greatest chance of failure being the one exposed to extreme heat.

The air inlet is detachable to facilitate ignition during start up operation or when re-igniting the combustion while already in operation. In the previous prototype (Fig. 2), access to this chamber is not possible once the hopper is already filled up. Hence, if the flame is quenched while the carbonizer is already in operation, the chamber could no longer be accessed for re-ignition.

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 'cooks' or carbonize the rice hulls in the immediate vicinity. Pyrolysis and partial combustion takes place 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 to the combustion chamber where they get combusted as the ambient air, coming out from the air inlet holes mixes with them thus smokeless emission are usually 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.

Performance test results

At least four test runs had been conducted to test and evaluate the performance of the new prototype in processing rice hull into biochar (carbonized rice hull or CRH). Some of these test runs fall during windy days, basing from data from an automatic weather station approximately 200m away from the test site. In all of the trials conducted, including those undocumented ones (which was done merely for the purpose of producing CRH for specific requirements), the machine performed satisfactorily basing from the generated output which is simply evaluated by its black color. Small amount of ash (less than one percent by weight) in the recovered output were observed mostly due to leaks of the covering of the outlet of the carbonizer. However, for CRH intended for soil conditioning or for organic fertilizer production, this is not critical.

Table 1 shows the results of the test runs using dried rice hulls taken from the rice milling facility of PhilRice. There was no incidence where excessive smoke or flame appeared in any of its openings as a result of operating it during windy conditions. In most instances, the prototype operates with smokeless emission, at least 85% of the time.

As observed however, the improved prototype has a lower capacity (24.2 kg/h average for the 4 test runs) as compared to the previous one which has an average capacity of 38.6 kg/h (Appendix Table 3). This was due to the fact that the new prototype is smaller in size. One full load of the hopper can accommodate only 6 sacks (~60 kg) of rice hull while that of the old prototype, 14 sacks (~140 kg).

The results of additional test runs also showed that the improved prototype can carbonize other materials such as wood, rice straw, and coconut husks which are readily available in most farms. In all of the test runs conducted, however, smoke was observed emanating from the auxiliary hopper. This could be due to the fact that the air spaces between the individual particles of the three materials tested are much larger than that those of the rice hull. This can however be solved by designing an appropriately covered feed chute to replace the louver every time materials much coarser than rice hull are to be processed by the machine.

Table 2 shows the performance data gathered during the conduct of the test runs. The machine was able to carbonize rice straw, coconut husk and small branches of trees at a rate of 12, 20, and 32.2 kg/h, respectively. In terms of charcoal yield, 24% yield was obtained from rice straw and wood while 18% for the coconut husk. As compared with other biomass carbonizer designs like the earth pit kiln, single drum kiln, and flat kiln having wood charcoal yield of 20.45%, 20.7, and 16.66%, respectively, as reported by [26], the charcoal yield of the prototype is higher. For the rice straw, a charcoal yield of 23,98% was obtained which followed the same trend as that obtained by [27] for a similar temperature of around 600^{o}C.

Results of these test runs provided an impression that the machine can also carbonize other materials such as bagasse, corn cobs, chopped corn stalks, and many others whose physical characteristics could approximate that of materials being used in the testing.

Potential as heat source

In terms of the heat generated, as based from temperature measurements at the combustion chamber, the improved prototype did not vary much with its predecessor when using rice hull material (Fig.5). Within a monitoring period of 80 minutes, the temperature was more or less stable at around 700^{o}C.

For other materials, on the other hand, the highest temperature reading was obtained from rice straw, however, the generated heat was not stable (Fig. 6). In most instances, wood yielded a lower temperature readings than rice hull, however it is the most stable among the three feedstocks used. This low temperature reading for wood could be due to the fact that no ignition took place at the combustion chamber as manifested by a smoky emission at the chimney. For wood, there is a need to provide larger air inlet holes so as to supply enough amount of air needed for combustion of the generated gases at the combustion chamber.

Applications: Challenges and Opportunities

Several applications of the prototype as heat source are currently being studied. The idea is, while producing charcoal, the generated heat is being utilized for other farming-related activity. Among the initiatives currently being pursued are as follows:

Carbonizer-pump-drip irrigation system

The new and improved design of the carbonizer is being used as a component of an irrigation system (Fig. 7) within a *Palayamanan*® site. In this case, the generated heat is being use to generate steam which in turn is used to drive a jet pump for use in drip irrigating tomatoes. Efforts are currently geared towards improving the system's water pumping capability as well as safety features.

Pilot testing in Aurora Province (Philippines)

Through a written request of the municipal agriculturist of the municipality of Maria Aurora, Aurora for a rice hull carbonizer that can be used by the rice farmers in the area, a unit of the improved design was provided to be used and operated by the farmers themselves. The use of carbonized rice hull in the growing of rice seedlings (to facilitate easy pulling of the seedlings) is becoming popular in the area, hence the need for a rice hull carbonizer. Some of the farmers have also the intention to try the machine in carbonizing coconut by-products (coconut husk and coconut shell) being abundant in the area. Initial report showed that the unit had been extensively used however, after three months of continued use, the inverted V partition of the combustion chamber is already showing some degree of deformations.

Poultry heating

An agricultural company in Nueva Ecija province has expressed an intention to use the carbonizer in the production of carbonized rice hull for its organic fertilizer production business while at the same time using the generated heat to supply the heat requirement of its poultry houses. The use of the carbonizer as heat source is expected to drastically reduce fuel costs.

Figure 7: An experimental setup of the carbonizer-pump-drip irrigation system.

SUMMARY AND CONCLUSION

The conduct of the study yielded an improved design of the PhilRice continuous rice hull carbonizer that has overcome the problems and concerns observed in the previous prototype. The new prototype offers potential for use not only in carbonizing rice hull but also other biomass wastes that can be commonly found in the farm. Likewise, the machine's capability to recover the heat generated during its operation offers a lot of potential benefits in the farm not only in terms of increasing farmers' income and productivity but also as a climate change adaptation strategy with some mitigation potential.

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APPENDICES

Appendix Table 1: Bill of materials of the improved rice hull carbonizer

QTY/UNIT	MATERIAL SPECIFICATION	UNIT PRICE, P	AMOUNT, P
2 shts	BI Sheet, 2mm	2,600.00	5,200.00
1 sht	BI sheet, 1.3mm	1,900.00	1,900.00
1 cut	GI pipe, 1” x 60 cm	40.00	40.00
1 cut	GI pipe, 2” dia x 70 cm L	220.00	220.00
2 kg	Welding rod	100.00	200.00
2 pcs	Angle bar, 3/16"thk x 1-1/2"	380.00	760.00
1 pc	Plain round bar, 3/8" dia. X 20'	176.00	176.00
1 pc	Flat bar, ¼” thk x 1” x 20’	385.00	385.00
1 liter	Paint (Primer)	150.00	150.00
2 bot	Lacquer thinner, 350 cc	24.75	49.5.00
4 pcs	Machine bolt, 3/8” dia x 1”	5.00	20.00
		TOTAL COST OF MATERIALS	9,100.50

Appendix Table 2: Bill of materials for the old prototype of the carbonizer (prior to design improvements)

QTY/UNIT	MATERIAL SPECIFICATION	UNIT PRICE, P	AMOUNT, P
4 shts	BI Sheet, 2mm	2,600.00	10,400.00
1 sht	BI sheet, 1.3mm	1,900.00	1,900.00
4 pcs	Plain round bar, 3/8” dia x 20 ft	176.00	704.00
4 pcs	Flat bar, ¼” thk x 1” x 20’	385.00	1,540.00
1 pc	Angle bar, 3/16" x 1" x 1"	180.00	180.00
2 kg	Welding rod	100.00	200.00
1 can	Aluminum paint, 1/4L	45.00	45.00
2 bot	Paint thinner	24.75	50.00
8 pcs	Machine bolt, 3/8” dia x 1”	2.00	16.00
		TOTAL COST OF MATERIALS	12,435.00

Appendix Table 3: Performance data of the second prototype [22].

Performance Parameter	Data
Ignition time	2.8 min
Input capacity	38.6 kg/h
CRH yield	39.4 %
Maximum temperature attained	860.1 ^{o}C
Purity of CRH	98.8%
Emission	
Oxygen	7.8%
Carbon monoxide	510 ppm
Carbon dioxide	6.8%