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Carbonization of Young Coconut (*Cocosnucifera*) Wastes

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A modified drum-type carbonizer was fabricated for the carbonization of young coconut waste. The major modification made was increasing the number of air inlets from four inlets per layer to eight inlets per layer, for three layers. Three tests were made by adjusting the number of air inlets opened. Water boiling test was performed using the three charred samples from the three tests. The first test had eight inlets opened, the second test had six, and the last test had five. The actual recovery and efficiency of the carbonizer were computed based on the data obtained. Observations were made on the charcoal produced and then it was subjected to water boiling test to determine its quality based on the stove's efficiency. The modified version produced higher amount of charcoal and low amount of uncharred young coconut waste than the original. It was also more efficient in producing young coconut waste charcoal. The original design took a longer time of carbonization operation. Results showed that the carbonizer with 8 air openings obtained the highest actual charcoal recovery of 33.13 % and highest efficiency of 64.8 % in the carbonization process. The water boiling test showed that the average thermal efficiency of the stove is 19.32 % and comparable with the thermal efficiency of the same stove using wood charcoal of 20 %. It means that the quality of charred young coconut waste is comparable to wood charcoal.

Key Words

Carbonization, Coconut wastes, Water boiling test, Thermal efficiency

1. Introduction

The use and conservation of energy and energy resources have been a very important and sensitive matter in the Philippines today. The Philippines imports over 47,605 m³ per day of crude oil and petroleum products from other countries to cover for the shortage in its energy production (Philippines Energy, 2012)¹⁾. However, due to the increasing costs of imported fuels, the government is trying to reduce the country's reliance on these imported fossil fuel products. In the recent years, researches and developments have been made to find alternative ways for a continuous and inexpensive energy generation.

The Philippines produces vast amount of biomass resources due to the large-scale production in agriculture (Elauria, 2013)²⁾. Most of the biomass resources come from

rice residues, sugar cane residues and coconut residues being the top three most important agricultural crops in the Philippines. The most common coconut residues are coconut shells and husks from mature coconut. Young coconut also produces large volume of waste and this could be a good source of energy for domestic use especially in ovens, furnaces for drying and stoves for cooking. The quality of young coconut waste as fuel could be improved if carbonized in order to reduce its water content and improve its heating value.

This paper presents the potential of young coconut waste through carbonization using the modified biomass carbonizer.

2. Methodology

2.1 Assessment of existing carbonizer

Four designs were assessed in order to determine the appropriate carbonizer for young coconut wastes namely: biomass pyrolyzer, open-type carbonizer, drum-type carbonizer and inclined-type carbonizer. The features of each design are presented below

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2.1.1 Biomass pyrolyzer

The design of the pyrolyzer (Fig. 1) is only suitable for biomass materials with small particle size (Unciano, 1979)³⁾. Each part is intended to handle fine materials. If used for bulky materials, the hopper can only contain several pieces of wood bolts (wood pieces with diameter ranging from 6.35 mm to 31.75 mm and length of 6.35 mm to 152.4 mm) or coconut waste at a time. The design of the combustion chamber is also suited for materials which are reduced in size. The opening which serves as pathway for the combustion chamber to the rotary discharge mechanism is also not designed for bulky materials. The discharge mechanism may encounter difficulties if large materials are used for the process.

2.1.2 Open-type carbonizer

The open-type carbonizer as shown in Fig. 2 is composed of a combustion chamber and a chimney. Both parts are cylindrical in shape but different in diameter size and length. The carbonizer is easy to handle and also requires less labor during the operation.

The desirable characteristic of this type of carbonizer is the simplicity in its design. It can be easily fabricated even without complex working equipment. The design is compact and can easily be handled by a single operator. The carbonizer is also made of light materials allowing the carbonizer to be moved in any place suitable for carbonization. The parts of the carbonizer can also be made of recycled materials such as used oil cans and metal sheets. However, the combustion of the materials in this design takes place outside the combustion chamber. The combustion chamber must be totally covered by the material to ensure carbonization. If materials with large

Fig. 2 Open-type carbonizer

particle size would be used, then it would be difficult to fully cover the combustion chamber. Also, not all the materials would be in contact with the combustion chamber. The materials which are not in contact with the chamber would not be subjected to carbonization.

2.1.3 Drum-type carbonizer

The drum type carbonizer is also composed of a combustion chamber and a chimney. The combustion chamber is usually a standard oil drum with a capacity of 208 L. Holes are also present on the sides of the drum to control the airflow during the operation. The holes are fitted with small threaded tubes that are covered with caps. They are located on different layers of the side of the oil drum. The drum is covered by a lid which has an opening where the chimney is attached. The carbonizer can be used to carbonize materials with large particle size like wood bolts. The bottom holes are usually open during the start of the operation to initiate the start of combustion. The other holes are sealed to prevent combustion in the other layers. The holes are sealed if the materials on a layer are already carbonized. The next upper holes are opened to start combustion on the upper layer. The drum type carbonizer is usually used to carbonize materials because of its high recovery. It has a recovery of about 37 %. The drum-type carbonizer is shown in Fig. 3.

The drum-type carbonizer is usually used to carbonize bulky materials like wood bolts. The combustion chamber provides containment for the materials to be carbonized. The chimney served as suction so that air will flow into the carbonizer, through the air inlets, during operation. The carbonizer can be easily lifted allowing it to

Fig. 1 Biomass pyrolyzer

Fig. 3 Illustration of a drum-type carbonizer

Fig. 4 Inclined-type carbonizer

be moved in areas suitable for carbonization. The materials used for fabrication can be easily obtained and have low cost (Estudillo, 1989)⁴⁾.

2.1.4 Inclined-type carbonizer

The inclined-type carbonizer (Fig. 4) is usually used to carbonize light materials and materials with small particle size. Some of these materials are rice hull and coir dust (also called cocopeat which is a spongy like residue from the processing of coconut husks). The materials are loaded on the hopper attached to the inclined bed

or the pre-drying area of the carbonizer. The inclination provides additional drying and also serves as the waiting or transport area of the carbonizer. At the end of the inclined bed is the carbonization area where the combustion takes place. Under the carbonization area is where the burner fuels are located. One of the problems during operation is the burst of flames from the carbonization area which can reach up to the inclined bed. This might be the result of the uncontrolled environment surrounding the carbonization bed. Another problem is the efficiency of the carbonizer that varies depending on the expertise of the operator handling it. This caused the carbonizer to have a low recovery of about 20-25 %. This carbonizer was designed to handle materials with small particle size. The structure or the framework of the design was not set to handle bulky materials.

2.2 Modification of the selected carbonizer

The design of the carbonizer was based on the drum-type carbonizer from the Forest Products Research and Development Institute (FPRDI). The major modification done was the increased number of air inlets per layer from four to eight. The modification was based on the observations made when the original design of carbonizer was tested using young coconut wastes.

The carbonizer was fabricated using a standard oil drum with a capacity of 208 L. A total of 24 holes were drilled at three different layers on the side of the oil drum. The first set of 8 holes was drilled one centimeter above the bottom of the drum. The second and third sets of holes were drilled above the circumferential markings on the surface of the drum.

The lid of the drum was removed and a 10.16-cm diameter hole was made at the center of the lid. Two pieces of 17.8 cm corrugated steel bar was welded on the lid to serve as handles when opening and closing the drum. Eight pieces of 0.635 cm x 1.27 cm stopper was made out of corrugated steel bar. The stoppers were welded just below the area where the lid was removed. These served as support for the lid when it is placed on or used to cover the drum.

The air inlets were made by cutting a 1.27 cm x 7.62 cm nipple pipe into two. The 1.27 cm x 3.81 cm nipple pipe was then welded on the holes drilled on the side of the drum. A 1.27 cm cap was used to cover or seal the air inlets. For ease of opening and closing the air inlets, a 1.27 cm x 1.27 cm pipe was welded on each cap. In combination with the pipe, a 25.4 cm corrugated steel bar was made so that it can be used in loosening or tightening the caps by inserting it into the pipe.

Fig. 5 Illustration of the modified drum-type carbonizer

The chimney of the carbonizer was made out of recycled galvanized iron (GI) sheet. It has a height of one meter and a diameter of four inches. The base of the chimney is a 20.32 cm x 20.32 cm recycled GI sheet which is attached and welded at the bottom end of the chimney. Another 20.32 cm x 20.32 cm recycled GI sheet was used to cover the hole on the lid of the drum after the carbonization process is finished. Fig. 5 shows the illustration of the modified drum-type carbonizer.

2.3 Moisture content determination

Fifteen sacks/cavans of young coconut were bought from a local market. The coconuts were split into two and then the coconut meat and water were removed. The samples were then transported to the laboratory for the moisture content determination and the drying process. Samples were heated in the oven maintained at 100 °C for 96 h to eliminate all the moisture and calculate the moisture content wet basis. Fig. 6 shows the young coconut waste sample used in the experiment.

Fig. 6 Young coconut waste samples used in the experiment

Three pairs of random samples were obtained from the batch of young coconut wastes to determine its initial moisture content. The recommended maximum moisture content of the sample for carbonization is 18 %. Using the initial moisture of the sample, the weight of water that corresponds to the 18 % moisture content was first calculated before the sample was subjected to oven drying. The first three samples were then subjected to oven-drying using the Carbolite convection oven until the samples had reached the required weight that corresponds to the required moisture content of 18 %.

2.4 Testing and performance evaluation of the modified carbonizer

2.4.1 Testing

Three tests were done in order to test and evaluate the performance and efficiency of the modified drum-type carbonizer. The difference in each test was based on the number of air inlets which were opened during the operation and carbonization process. The air inlets in one layer were opened at a time but not all layers at the same time. The first layer of air inlets opened was the bottom layer, next is the middle layer, and last is the top layer. In the first test, all or eight air inlets in one layer were opened while in the second test, only six air inlets were opened. Lastly, in the final test, five air inlets were opened to limit the supply of air similar to the second test.

The operation started by opening the required number of air inlets of the carbonizer. The bottom layer of air inlets was first opened to initiate combustion. A small pile of young coconut waste was loaded into the carbonizer to initiate the combustion process. Approximately 50 mL of kerosene was poured into the pile of young coconut waste inside the carbonizer and ignited with a piece of burning paper.

When the combustion process was observed to be continuous, more young coconut waste was added until the carbonizer was full. The lid was placed to close the carbonizer and then the chimney was placed on top of the hole of the lid to serve as a suction for the exhaust gases. The duration of the process was determined and recorded using a stopwatch. The weight of the young coconut waste loaded to the carbonizer was obtained by subtracting the weight of the remaining coconut waste after loading from the total weight of coconut waste before loading.

During the process, the air inlets served as observation holes to determine if the young coconut waste had been carbonized. Ember or burning fixed carbon and some blaze or fire were observed from the air inlets indicating that the carbonization process was already

finished. When the carbonization process was done, the air inlets of the bottom layer were closed and then the air inlets of the middle layer were opened. The same procedure was done for the middle and top layers. The thin volume of smoke produced at the end of the process also indicated that the carbonization of the young coconut waste was completed. All the air inlets were closed and the chimney was removed from the lid. The hole on the lid was covered by the 20.32 cm x 20.32 cm GI sheet to prevent continuous combustion. The charcoal produced was allowed to cool down before the charred young coconut waste was separated from the uncharred manually. The weight of both the charred and uncharred young coconut waste were obtained and recorded. The data obtained was used to determine the recovery and efficiency of the modified drum-type carbonizer.

2.4.2 Performance evaluation

The efficiency of a system dictates how well it could perform its tasks whether it's a conversion or transport process. It also compares the actual performance of a system to a theoretical or ideal performance that it can accomplish. Combustion calculation helps in determining the efficiency of a carbonization process. Different parameters were gathered before and after the process. The values of these parameters were then used to measure the performance of the carbonizer.

Some of the parameters that will be obtained or measured before and after the operation are moisture content, initial weight of the material, weight of the charcoal recovered and weight of the container. Other values like weight of the volatile matter will be obtained from computations. These data are needed in order to compute for the actual and maximum recovery of the system. Percent actual recovery, R_{actual} represents the actual weight of charcoal produced over the initial weight of sample expressed in percentage while percent maximum recovery, R_{max} shows the maximum weight of charcoal that can be recovered over the initial weight of sample expressed in percentage. The maximum weight of charcoal that can be recovered is the sum of the weight of fixed carbon and ash present in the sample which can be computed by subtracting the weight of water and volatile matter from the initial weight of sample. The equations for actual recovery, maximum recovery and efficiency are presented in Eqs (1), (2) and (3), respectively.

$$R_{actual} = \frac{W_{charcoal}}{W_{initial}} \times 100 \quad (1)$$

where:

R_{actual} is the actual recovery of the system (%)

$W_{charcoal}$ is the weight of charcoal recovered (kg)

$W_{initial}$ is the initial weight of samples (kg)

$$R_{max} = \frac{W_{initial} - W_m - W_{vm}}{W_{initial}} \times 100 \quad (2)$$

where:

R_{max} is the maximum recovery of the system (%)

$W_{initial}$ is the initial weight of wet samples (kg)

W_{vm} is the weight of the volatile matter (kg)

W_m is the weight of water in the sample (kg)

$$E_{system} = \frac{R_{actual}}{R_{max}} \times 100 \quad (3)$$

where:

E_{system} is the system efficiency (%)

R_{actual} is the actual recovery of the system (%)

R_{max} is the maximum recovery of the system (%)

2.5 Evaluation of the charcoal produced using water boiling test

The water boiling test (WBT) is a method of determining the efficiency and the performance of a stove. It is a rough estimation of the cooking process which helps in designing stoves through the observation of energy transfer from the fuel to the cooking pot. This process was used in determining the quality of the charcoal produced through the efficiency of the stove. Three sets of young coconut waste charcoal were produced from the three tests of carbonization using the modified drum-type carbonizer. Each set of charcoal produced was subjected to three repetitions of water boiling test. The quality of flame produced and combustion characteristics of each set of charcoal were observed. The actual water boiling test was shown in Fig. 7.

Only one stove was used for testing the three sets of charcoal. The stove had a weight of 5.8 kg. It was loaded

Fig. 7 Water boiling test for the charcoal

with 0.25 kg of young coconut waste charcoal as fuel for the test. The same amount of charcoal was used for the other remaining tests. Kerosene was poured into the charcoal and it was ignited with a piece of burning paper. Observations were made while initial combustion of the charcoal took place.

The burning rate, specific fuel consumption and thermal efficiency of each test were determined using the data obtained from the test. Eqs. (4), (5) and (6) were used for the computations.

$$\text{Burning Rate} = \frac{\text{Weight of fuel consumed (kg)}}{\text{Total time to boil (s)}} \quad (4)$$

Total time to boil is the total time from the start of heating until the water boils

$$\text{Specific Fuel Consumption} = \frac{\text{Weight of fuel consumed (kg)}}{\text{Weight of water boiled}} \quad (5)$$

Weight of water boiled is equivalent to the initial weight of water

$$\begin{aligned} \text{Thermal Efficiency} &= \frac{4.186 \times \text{Initial weight of water (g)} \times (\text{Final temp} - \text{Initial temp}) + m_g \times h_{fg}}{\text{LHV} \times \text{Weight of fuel consumed (kg)}} \\ &\times 100 \end{aligned} \quad (6)$$

Where:

m_g is the weight of water lost during boiling

h_{fg} is the latent heat of vaporization

3. Results and Discussion

3.1 Physico-chemical properties of young coconut wastes

The physical and chemical properties of young coconut wastes are very important for the design of a carbonizer. The physical properties will help in determining the materials and dimensions of the design to be made. Some of the physical properties are moisture content, bulk density, and surface area. On the other hand, the chemical properties of young coconut wastes will determine its behavior or reaction during combustion or carbonization. The heating value, proximate analysis and ultimate analysis are some of these chemical properties.

Heating value is the amount of heat contained in a fuel and is released during the process of combustion (Enotes, 2011)⁵⁾. The heating value of young coconut is 19.43MJ/kg. Proximate analysis is a method of determining how the fuel will react if it is subjected to heat. It also shows some components of the fuel like volatile matter, fixed carbon and ash content. Ultimate analysis is a method of determining the major elements found in fuels. This method is useful in the heat-balance calculation of fuels. The heat-balance calculation helps determine and quantify the

Table 1 Physico-chemical properties of husk, shell and young coconut waste

PROPERTIES	HUSK	SHELL	YOUNG COCONUT WASTE
Higher Heating Value (MJ/kg)	20.3	18	19.43
Proximate analysis			
Volatile matter, %	46.4	77.19	55.21
Fixed Carbon, %	24.9	22.1	23.96
Ash, %	28.7	0.71	20.83
Ultimate analysis			
Carbon, %	50.29	46.01	48.51
Hydrogen, %	5.05	6.04	5.25
Oxygen, %	39.63	47.75	41.33
Nitrogen, %	0.45	0.19	0.37

Note: Based on the results of ultimate and proximate analysis, dry basis

percentage of every compound present in the product of combustion like carbon dioxide, water vapor and nitrogen. It also helps in the estimation of air requirements for the combustion process. The basic elements found in fuels are carbon, hydrogen, oxygen, and nitrogen. The summary of the physico-chemical properties of young coconut waste is presented in Table 1.

3.2 Assessment of existing carbonizer

The proper design of carbonizer for the carbonization of young coconut waste was selected based on the assessment of the existing designs of carbonizer. The design selection was generally based on how the carbonizer can contain and handle the young coconut waste during operation and the cost of fabrication.

The biomass pyrolyzer, open-type carbonizer, and inclined-type carbonizer were not selected because they can only be used for small particle size raw materials. Only the drum-type carbonizer can accommodate the size of the young coconut waste hence this was considered. Also the cost of fabrication of drum-type carbonizer is lower considering the availability of used oil drum and simplicity in design.

The initial results of the carbonization of young coconut waste using the existing drum-type carbonizer showed difficulty in carbonizing the raw material. Based on the observations, the initial combustion was too slow. With only four air inlets per layer, airflow into the carbonizer was limited, thus, hindering the combustion process to continue. Hence, the existing drum-type carbonizer was modified.

3.3 Performance testing of the modified drum-type carbonizer

Observations from the testing and operation of the drum-type carbonizer were considered for the modification so that it can be adopted for the carbonization of young coconut waste. The drum-type carbonizer was usually used to carbonize wood bolts.

From the start of the operation, it was observed that there was a difficulty in starting the combustion of the young coconut waste. All four air inlets of the bottom layer were opened before the initial combustion was started. The small pile of young coconut husk mixed with kerosene cannot sustain the flame produced from the ignited piece of burning paper. The flame only lasted for about one to two minutes and then the burning process slowly stopped. Several trials were done to start the initial combustion of the coconut waste. Normally 50 mL of kerosene is enough to start the fire and establish steady fire but it in the initial test another 100 mL of kerosene was added to stabilize the combustion.

The observations from the operation of the drum-type carbonizer were affected by the air flow into the carbonizer. The poor start of initial combustion was caused by insufficient air flow through the air inlets of the carbonizer. The supply of air is not enough to maintain the flame that started the combustion process. The same reasoning can be applied to the increase and decrease of volume of smoke during the operation. The lid was slightly opened so that additional amount of air will flow into the carbonizer and help in increasing the rate of combustion. Since the air inlets allow the flow of air into the carbonizer, the current number of air inlets on the carbonizer is not enough to provide the amount of air for the carbonization of young coconut waste. Increasing the number of air inlets will increase the flow of air. This will greatly help in the initial combustion of the process. Also, it will allow the young coconut waste to achieve total carbonization. The current number of air inlets on the original design was four

inlets per layer. Increasing the number of air inlets by 100 % means that the air flow will also be increased by 100 %. Thus, the idea of modifying the number of air inlets per layer from four inlets to eight inlets was done. The doubled amount of air flow should be sufficient for the quick start of initial combustion and for the continuous carbonization.

Table 2 shows the data obtained during the carbonization of young coconut wastes under different conditions namely: 8 openings, 6 openings, 5 openings in each of the three layers in the drum-type carbonizer. The last column represents the data obtained using the original drum-type carbonizer (with 4 air openings).

Actual recovery (%) is based on a the ratio of the actual weight of charcoal from the initial weight of raw material while maximum recovery (%) is based on the ratio of theoretical weight of charcoal that can be recovered from the initial weight of raw material. The theoretical weight of charcoal is computed by multiplying the initial weight of raw material by the combined % of fixed carbon and % ash from the proximate analysis.

Based on the results of the test, Table 2 shows that all the data obtained from the modified design were more acceptable than the data obtained from the original design. The modified version produced higher amount of charcoal and low amount of uncharred young coconut waste than the original. It was also more efficient in producing young coconut waste charcoal. On the other hand, the original design took a longer time of operation which made it less desirable when large amount of samples will be carbonized. During the operation, it was observed that the young coconut waste was easily ignited and that the initial combustion process was easily started using the modified drum-type carbonizer. The carbonization time is even less than half of the carbonization time using the original design.

The results of the test of the modified drum-type carbonizer showed that the test for 8 openings produced the highest amount of charcoal which was 8.15 kg

Table 2 Results of carbonization test using the modified-drum type carbonizer with 8, 6, 5 air openings and the original drum-type carbonizer

ITEM	NUMBER OF AIR INLETS OPEN			
	8	6	5	Original (4)
Initial weight of cocowaste (kg)	24.6	25.8	25.65	29.45
Weight of charcoal recovered (kg)	8.15	7.95	8.05	6.8
Weight of uncharred cocowaste (kg)	0.15	2.2	2.5	2.5
Volatile matter (kg)	12.022	13.206	12.983	16.41
Actual recovery (%)	33.13	30.81	31.38	23.09
Rmax, Maximum recovery (%)	51.13	48.81	49.38	44.28
Efficiency of the system (%)	64.8	63.13	63.55	52.15
Time duration (min)	54.77	60.9	68.47	137.22

equivalent to 33.13 % actual charcoal recovery compared to the 6 openings and 5 openings with 30.81 % and 31.38 % respectively. The 8 openings also yielded the lowest amount of uncharred cocowaste in comparison with the other two openings. Based on the carbonization efficiency, the test with all air inlets opened is also the most efficient having 64.8 %, followed by the 5 openings having 63.55 %, and lastly, the 6 openings with an efficiency of 63.13 %.

3.4 Quality of charred young coconut waste

The quality of the charcoal produced was observed after they were removed from the carbonizer. Some charcoal produced from 8 openings showed some white discoloration and ash-like materials present on the surface or edge of the charcoal. Bluish discoloration on the charcoal was also present not only from 8 openings but also with the other openings. Uncharred coconut wastes were also found from all the tests of carbonization. Some portion of the uncharred coconut waste was still brown in color while the remaining part was black. The high quality charcoal produced from all the tests has no discolorations and had a shiny-black color. The different qualities of charcoal produced are shown in Fig. 8.

Table 3 shows the results of the water boiling test. The cookstove registered an average thermal efficiency of 19.32 %. This is almost comparable with the thermal efficiency of the same stove using wood charcoal of 20 % (Lozada, 1980)⁶⁾. It means that the quality of charred young coconut waste is comparable to wood charcoal.

The flame of the burning fuel had a yellowish color at the tip and a bluish color at the base. However, the process of combustion was observed to be continuous on all the sets of charcoal after the initial combustion was started.

4. Conclusion

The study showed that young coconut waste can be carbonized using the modified drum-type biomass carbonizer. The initial ignition is steady and carbonization of young coconut waste can be achieved easily with minimal intervention.

The performance of the modified drum-type carbonizer expressed in terms of actual charcoal recovery and carbonization efficiency is far better than that of the existing drum-type carbonizer. The performance of the modified drum-type carbonizer is highest when there are 8 air openings in each of the three layers of the drum.

The quality of the charred young coconut waste is almost complete and comparable with that of the ordinary wood charcoal when used in the same cookstove. It can therefore be said that the young coconut waste can be processed and be a good source of energy for cooking.

Fig. 8 Different qualities of charcoal from carbonization (Note: A was produced from the 8 openings while B, C and D were produced from other openings)

Table 3 Water boiling test for the three sets of charcoal used from 8, 6 and 5 openings

ITEM	CHARCOAL USED		
	8 openings	6 openings	5 openings
Weight of container (kg)	0.4	0.4	0.4
Initial weight of water (kg)	2.1	2.1	2.1
Total weight of fuel placed in the stove (kg)	0.25	0.25	0.25
Weight of water left (kg)	1.98	1.98	1.99
Weight of water evaporated (kg)	0.12	0.12	0.11
Weight of charcoal left (kg)	0.097	0.093	0.1
Weight of unburned fuel (kg)	0.097	0.093	0.1
Initial temperature (°C)	33.43	33.17	33.77
Final temperature (°C)	98.93	98.83	99
Final time after boiling for approximately 5 minutes (min)	21	19.25	21.69
Total time to boil (min)	15.38	14.78	16.88
Burning rate (kg/s)	0.0099	0.0106	0.0089
Specific fuel consumption	0.0773	0.0793	0.0754
Thermal efficiency (%)	19.37	18.92	19.67

References

- 1) Philippines Energy. Background. Retrieved September 9, 2011 from <http://philippinesenergy.com/> (2012)
 - 2) Elauria, J. C.; Elauria, M. M., *J. Jpn. Inst. Energy*, **92**(1), 83-88 (2013)
 - 3) Unciano, H. C.; Briones L. P., Design and Development of a Biomass Pyrolyzer System, Unpublished terminal report, University of the Philippines Los Baños, College, Laguna, (1979)
 - 4) Estudillo, C. P., Development of an Equipment for the Continuous Carbonization of Wood, Unpublished terminal report, University of the Philippines Los Baños, College, Laguna, (1989)
 - 5) Enotes., Heat of combustion. Retrieved September 26, 2011 from http://www.enotes.com/topic/Heat_of_combustion, (2011)
 - 6) Lozada, E., Thermal Efficiency of Various Biomass Cookstoves in the Philippines, npublished Terminal Report, (1979)
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