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PRODUCTION OF ENERGY STICKS FROM THE SOLID WASTE OF STRAW MUSHROOM CULTIVATION

Prayong Keeratiurai
Department of Civil Engineering, Faculty of Engineering, Vongchavalitkul University, Nakhon Ratchasima Province, Thailand
E-Mail: keeratiurai_pray@windowslive.com

ABSTRACT

One community in Khon Buri district of Nakhon Ratchasima province was cultivated more straw mushroom. Cultivated straw mushroom will cause a lot of solid waste. The solid waste from straw mushroom cultivation created environmental problems and affected to the quality of straw mushroom cultivation. This research had the idea to study the utilization of solid waste of straw mushroom cultivation and solved environmental problems. The production of renewable energy in the form of the charcoal powder compressed to sticks and the green charcoal sticks from the solid waste of straw mushroom cultivation. This research also evaluated the heating value from the green charcoals and the charcoal powder briquettes that compared to normal wood charcoals. The method of green charcoal production was the solid waste from straw mushroom cultivation was crushed then was mixed with tapioca starch and was done extrusions. In addition, this study also brought the solid waste from straw mushroom cultivation to produce the charcoal powder briquette. By bringing it burned to black charcoal, then crushed and mixed with tapioca starch and compressed into the charcoal powder briquette. Then took the green charcoal sticks and the charcoal powder briquette, were tested to evaluate the heating value with the Bomb Calorimeter. This study was the water boiling to measure temperature of water increases with time. The heating value of the green charcoal sticks and the charcoal powder briquette were compared with results from the normal wood charcoal that was fuel in the same manner. This study tested to three times, using the quantities of the green charcoal sticks were 1 kg, 2 kg and 3 kg, the charcoal powder briquette were 1 kg, 2 kg and 3 kg and the normal wood charcoal were 1 kg, 2 kg and 3 kg. The results of this study showed the amount of the energy sticks had directly affects to the heating value and the duration of the fire. The quantities of green charcoal were 1 kg, 2 kg and 3 kg had the heating value were 0.339 kW, 0.611 kW, and 0.985 kW, respectively. The quantities of charcoal power briquette were 1 kg, 2 kg and 3 kg had the heating value were 0.603 kW, 0.753 kW, and 1.005 kW, respectively. And the quantities of normal wood charcoal were 1 kg, 2 kg and 3 kg had the heating value were 0.703 kW, 0.746 kW, and 0.921 kW, respectively. The results of this study also showed that the heating value per unit of the green charcoal, the charcoal power briquette, and the normal wood charcoal were 0.324±0.017 kW/kg, 0.438±0.144 kW/kg, and 0.461±0.212 kW/kg, respectively. The charcoal power briquette and the normal wood charcoal had the duration of the fire were 83.33±25.17 minutes and 90.00±30.00 minutes, respectively while the green charcoal had the duration of the fire was 66.67±12.58 minutes. This study concluded that the green charcoal and the charcoal power briquette that made from the solid waste of the straw mushroom cultivation could be used instead of the normal wood charcoal.

Keywords: straw mushroom, heating value, green charcoal, charcoal power briquette.

INTRODUCTION

The results of survey one community in Khon Buri district of Nakhon Ratchasima province found that this community was cultivated more straw mushroom. Cultivated straw mushroom will cause a lot of solid waste. The solid waste from straw mushroom cultivation created environmental problems as air, wastewater and soil pollution and affected to the quality of straw mushroom cultivation. This research had the idea to study the utilization of solid waste of straw mushroom cultivation and solved environmental problems. The production of renewable energy in the form of the charcoal powder compressed to sticks and the green charcoal sticks from the solid waste of straw mushroom cultivation. This research also evaluated the heating value from the green charcoals and the charcoal powder briquettes compared to normal wood charcoals.

The process of preliminary feasibility study was survey the quantities of the solid waste from straw mushroom cultivation, compaction and forming method in sticks of green charcoal and charcoal powder briquettes. This research also measured and collected physical data of the green charcoal sticks and the charcoal powder briquettes then analyzed the qualities of the 2 type of energy sticks as follows:

$$\text{Density } (g/cm^3) = \text{Weight } (g) / \text{Volume } (cm^3) \quad (1)$$

Moisture content was the amount of water was in the energy sticks. It could be analyzed by weighing of the energy sticks before baking and after baking, and calculate the moisture from equation as follow.

$$\text{Moisture content } (\%) = [(w1 - w2) / w1] * 100 \quad (2)$$

When: w1 was the weight of the energy stick before drying (g)
w2 was the weight of the energy stick after drying (g)

This research also evaluated the heating value from the green charcoals and the charcoal powder briquettes that were produced from the solid waste of the

straw mushroom cultivation, compared to normal wood charcoals from equation as follow.

$$Q = m * c * \Delta t \quad (3)$$

When: Q = heating value (kW)
m = mass of water (kg)
c = specific heat = 4.186 J kg^{-1} $^oC^{-1}$, at 25 degree Celsius and pressure 1 atm.
Δt = change in temperature (= final - initial temperature)

Heating value of fuel test

Bomb Calorimeter was used for the calculation of the change of internal energy due to the chemical reaction. Measuring the internal energy was directly related to the electron energy. Chemical substances with high electron energy were high internal energy as well. When two elements such as hydrogen and oxygen were reacted to form water ($2H_2 + O_2 => 2H_2O$). Energy was released and allows the water temperature in water bath up. Higher temperatures would show the change of internal energy occurs. Assigned to the heat that was released from the chemical reactions that occur within the Bomb Calorimeter was equal to the energy was released by the reaction of the same type that occurred in the open air. And it would assume that there was no difference between the enthalpy and the internal energy.

Heat of combustion

Heat of combustion or burning was a chemical reaction between oxygen (O_2) and organic substances. When burning up carbon and hydrogen in organic substances would react with the oxygen and formed as carbon dioxide (CO_2) and water (H_2O). Such chemical reaction was exothermic reaction which would release the heating values. The experiments would occur burning within Bomb Calorimeter to measure the heating values that were released due to reactions.

The heat that was released when burning was called the heating value of fuel. In general, the heating values would be divided into two types, namely higher heating value (HHV) and lower heating value (LHV). HHV was calculated with including to the heat of condensation, which was about 10% of the total heating values. While LHV was not calculated with including to the heating value due to this heat of condensation. HHV was higher than LHV. So the heating value was often used as LHV.

Bomb calorimeter

Bomb Calorimeter works by the principle of Calorimetry. Calorimetry is the scientific principles of measuring the heat energy. The heat energy is released or absorbed by a chemical or physical process. The change of chemical or physical process occurs in constant-volume conditions of Bomb Calorimeter. The heating value is the change of internal energy. Hydrocarbons contain carbon, hydrogen, and oxygen, are the main components. It can easily react with oxygen. General reactions of the combustion of hydrocarbons with oxygen as shown in the equations were below.

$$C_xH_yO_z+O_2(g) \longrightarrow CO_2(g)+H_2O(g)$$

$$C_xH_yO_z+(x+y/4-z/2)O_2(g) \longrightarrow (x)CO_2(g)+(y/2)H_2O(g)$$

Bomb calorimeter was used in this study was performed by burning the green charcoals, the charcoal powder briquettes and the normal wood charcoals with oxygen in a container with constant volume. The container was surrounded by water. The heat generated was absorbed by the surrounding water. Measuring the temperature change of the water would be able to calculate the heating value. The heating values were measured from the sample combustion were the change of internal energy in the Initial state to final state.

METHODOLOGY

This research had the idea to study the utilization of solid waste of straw mushroom cultivation and solved environmental problems. The production of renewable energy in the form of the charcoal powder compressed to sticks and the green charcoal sticks from the solid waste of straw mushroom cultivation. This research also evaluated the heating value from the green charcoals and the charcoal powder briquettes compared to normal wood charcoals.

The process of preliminary feasibility study was survey the quantities of the solid waste from straw mushroom cultivation, compaction and forming method in sticks of green charcoal and charcoal powder briquettes. The samples were farmers who cultivated straw mushroom in suburban areas of Khon Buri district, Nakhon Ratchasima province. The samples of the solid waste from straw mushroom cultivation were collected and taken to test various properties in the laboratory. This research also measured and collected physical data of the green charcoal sticks and the charcoal powder briquettes then analyzed the properties of the 2 type of energy sticks. The method of green charcoal production was the solid waste from straw mushroom cultivation was crushed then was mixed with tapioca starch and was done extrusions with the screw compressor. The green charcoal sticks were dried in an oven at 105 degree Celsius for 48 hours as shown in Figure-1.

Figure-1. The green charcoal sticks in dry condition.

In addition, this study also brought the solid waste from straw mushroom cultivation to produce the charcoal powder briquette. By bringing it burned to black charcoal, then crushed and mixed with tapioca starch and water in ratio as the solid waste from straw mushroom cultivation 5 kilograms, tapioca starch 0.5 kilograms and water 2 liters. They was mixed and compressed into the charcoal powder briquette with the screw compressor again as shown in Figure-2. The charcoal powder briquettes were dried in an oven at 105 degree Celsius for 48 hours.

Figure-2. The charcoal powder briquettes in dry condition

The green charcoal sticks and the charcoal powder briquettes were tested with size measurement, weighting, and compared the 2 type of energy sticks with the normal wood charcoals. The green charcoal sticks, the charcoal powder briquettes and the normal wood charcoals were analyzed density, volume, moisture contents, heating value, combustible time. That took the green charcoal sticks and the charcoal powder briquette, were tested to evaluate the heating value with the Bomb Calorimeter. This study was the water boiling to measure temperature of water increases with time every 5 minutes. The heating value of the green charcoal sticks and the charcoal powder briquettes were compared with results from the normal wood charcoals that were fuel in the same manner. This study tested to three times, using the quantities of the green charcoal sticks were 1 kg, 2 kg and 3 kg, the charcoal powder briquette were 1 kg, 2 kg and 3 kg and the normal wood charcoal were 1 kg, 2 kg and 3 kg.

RESULTS

The various properties of the energy sticks of the 3 species were analyzed by weighting, measuring shapes. Then they were calculated to find the average of volume, density, and the moisture content as shown in Table-1.

Table-1. The average of the various properties of the energy sticks of the 3 species.

Energy sticks	**Weight** (g)	**Moisture** (%)	**Volume** (cm^3)	**Density** (g/cm^3)
Green charcoal sticks	67.07± 7.970	3.59± 1.900	84.00± 4.002	0.798± 0.087
Charcoal powder briquettes	139.8± 15.200	2.28± 0.702	82.61± 1.826	1.692± 0.177
Normal wood charcoals	50.82± 6.600	2.24± 1.263	71.43± 12.114	0.711± 0.106

The heating values were evaluated since the normal temperature to 100 degrees Celsius. The evaluations of heating values were the water boiling in same volumes and measured temperature of water increases with time every 5 minutes. The heating values of energy sticks were calculated by this equation as $Q = m * c * \Delta t$. The heating value of the green charcoal sticks and the charcoal powder briquettes were compared with results from the normal wood charcoals as shown in Table-2.

Table-2. The heating value of the energy sticks of the 3 species.

Energy sticks	**Heating value from the amount of energy sticks** (kW)			**Average of heating value per amount of energy sticks** (kW/kg)
	1 kg	**2 kg**	**3kg**	
Green charcoal sticks	0.339	0.611	0.985	0.324±0.017
Charcoal powder briquettes	0.603	0.753	1.005	0.438±0.144
Normal wood charcoals	0.703	0.746	0.921	0.461±0.212

The relationship between the accumulations of heating value to increases with the duration to boil water since the normal temperature to 100°C of the 3 types of energy sticks in 1 kg was found trends of the heating value of the wood charcoal above the charcoal powder briquette and the green charcoal, respectively. Which they were to be noted that the trends of the heating value of the charcoal powder briquette higher than the green charcoal as shown in Figure-3. While measuring the final of accumulated heating value at temperature of 100°C was found that the wood charcoal was 3.516 kW, the green charcoal was 3.286 kW, and the charcoal power briquette was 3.013 kW, respectively. It showed that the process of transformation of the solid waste of the straw mushroom cultivation into charcoal powder had affected with the value of heating rate over the duration of the fire.

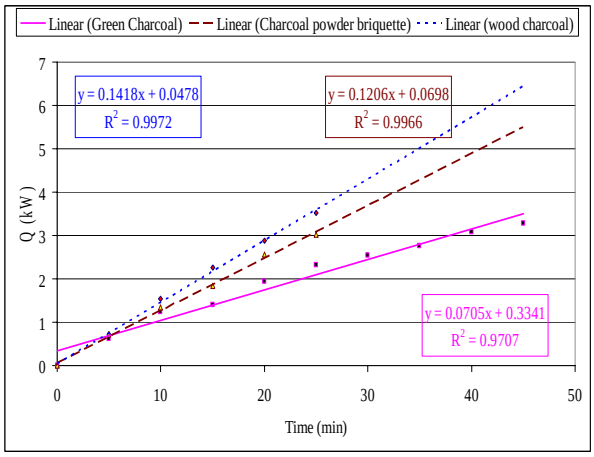

Figure-3. The relationship between the accumulations of heating value to increases with the duration to boil water since the normal temperature to 100°C of the 3 types of energy sticks in 1 kg.

The results of this study on the three types of energy sticks that were increased to 2 kg were found that trends of the heating value of the charcoal powder briquette above the wood charcoal and the green charcoal, respectively. Which they were to be noted that the trends of the heating value of the charcoal powder briquette higher than the green charcoal as shown in Figure-4. While measuring the final of accumulated heating value at temperature of 100°C was found that the wood charcoal was 3.572 kW, the green charcoal was 3.286 kW, and the charcoal power briquette was 3.013 kW, respectively. All three types of energy sticks in 1 kg and 2 kg had the heating values at 100 °C to similar. But period of the water boiling from normal temperature until 100 °C were not equal. More amount of energy sticks used a shorter period in the boiling.

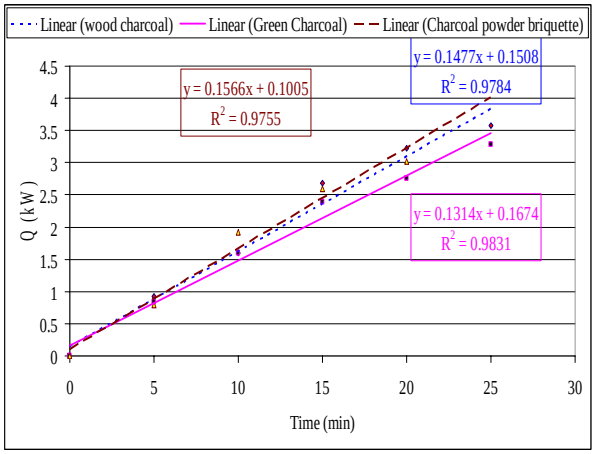

Figure-4. The relationship between the accumulations of heating value to increases with the duration to boil water since the normal temperature to 100°C of the 3 types of energy sticks in 2 kg.

The relationship between the accumulations of heating value to increases with the duration to boil water since the normal temperature to 100°C of the 3 types of energy sticks in 3 kg was found that the trends of the heating value of the green charcoal above the charcoal powder briquette and the wood charcoal, respectively. Which they were to be noted that the trends of the heating value of the charcoal powder briquette lower than the green charcoal as shown in Figure-5. While measuring the final of accumulated heating value at temperature of 100 °C was found that the wood charcoal was 3.872 kW, the green charcoal was 3.187 kW, and the charcoal power briquette was 3.013 kW, respectively. All three types of energy sticks in 1 kg, 2 kg and 3 kg had the heating values at 100°C to similar. But period of the water boiling from normal temperature until 100°C were not equal. More amount of energy sticks used a shorter period in the boiling.

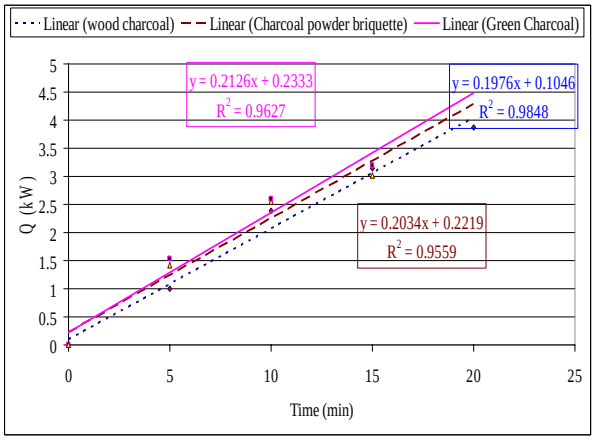

Figure-5. The relationship between the accumulations of heating value to increases with the duration to boil water since the normal temperature to 100°C of the 3 types of energy sticks in 3 kg.

The results of this study also showed the relation between amount of energy sticks and the period of the water boiling from normal temperature until 100°C. The period of the water boiling was inversely proportional to the amount of energy sticks as shown in Table-3.

Table-3. The period of the water boiling from normal temperature until 100°C.

Energy sticks	Amount of energy sticks		
	1 kg	2 kg	3kg
Green charcoal sticks	45 (min)	25 (min)	15 (min)
Charcoal powder briquettes	25 (min)	20 (min)	15 (min)
Normal wood charcoals	25 (min)	25 (min)	20 (min)

Table-3 showed the heating of 3 types of energy sticks were found the charcoal powder briquettes provided the high heating value and brought the water temperature changes from normal temperature to 100°C in a shorter time than the green charcoal sticks and the normal wood charcoals. The results also showed the relationship between temperatures increasing with time of the water boiling with all three types of energy sticks with weighs 1 kg as shown in Figure-6. The rate of temperature increase versus time were similar to the normal temperature of boiling water at 100°C, with the charcoal powder briquette and the wood charcoal. While the rate of increase of temperature versus time was minimum from the water boiling using the green charcoal sticks. The result showed that the green charcoal provided the lowest rate of heating value compared to the time when the weights of energy stick was 1 kg.

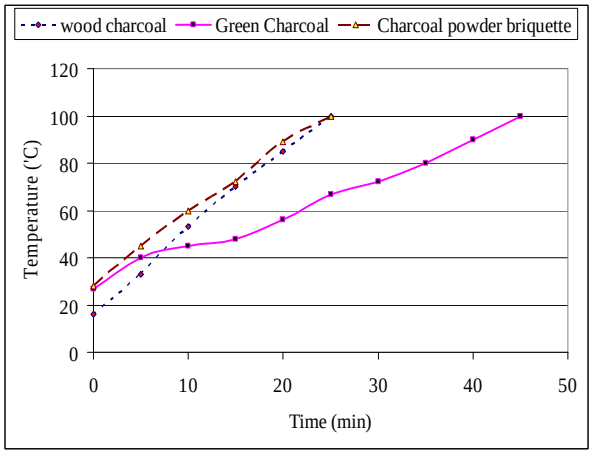

Figure-6. Relationship between temperatures increasing with time of the water boiling with all three types of energy sticks with weighs 1 kg.

When studied by adding of energy sticks were 2 kg for the water boiling from normal temperature to 100°C was found the charcoal powder briquette provided the highest rate of heating value compared to the time. While the wood charcoal and the green charcoal provided the rate of heating value compared to the time were similar as shown in Figure-7. This graph showed the relation between temperatures increasing with time of the water boiling with all three types of energy sticks with S-curve.

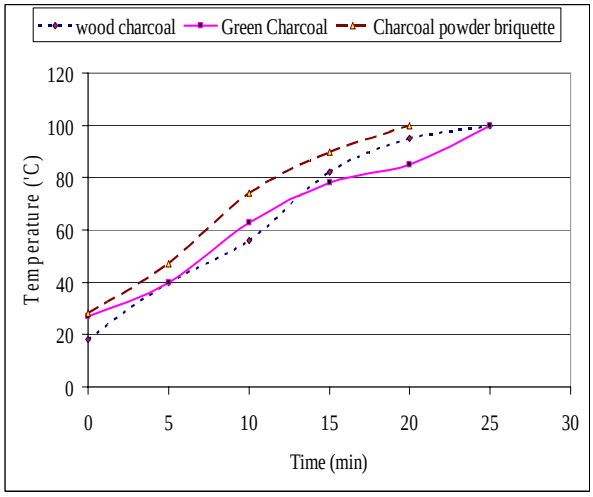

Figure-7. Relationship between temperatures increasing with time of the water boiling with all three types of energy sticks with weighs 2 kg.

The results also showed the relationship between temperatures increasing with time of the water boiling with all three types of energy sticks with weighs 3 kg as shown in Figure-8. The rate of temperature increase versus time were similar to the normal temperature of boiling water at 100°C, with the charcoal powder briquette and the green charcoal. While the rate of increase of temperature versus time was minimum from the water boiling using the wood charcoal sticks. The result showed that the wood charcoal provided the lowest rate of heating value compared to the time and the charcoal powder briquette provided the highest rate of heating value compared to the time when the weights of energy stick was 3 kg.

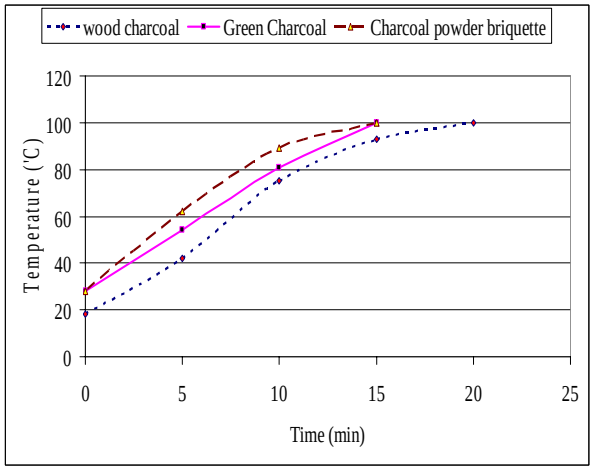

Figure-8. Relationship between temperatures increasing with time of the water boiling with all three types of energy sticks with weighs 3 kg.

Table-4. The duration of the fire from beginning to the fire extinguished.

Energy sticks	Amount of energy sticks		
	1 kg	2 kg	3kg
Green charcoal sticks	55 (min)	65 (min)	80 (min)
Charcoal powder briquettes	60 (min)	80 (min)	110 (min)
Normal wood charcoals	60 (min)	90 (min)	120 (min)

Table-4 showed the duration of the fire from beginning to the fire extinguished. The charcoal powder briquettes and the wood charcoals had the period of flammability similar. The heating value of them more than the green charcoal sticks. The results of this study also showed that the amount of the energy sticks had directly affects to the duration of the fire.

CONCLUSIONS

This research had been guided in the elimination of the solid wastes of the straw mushroom cultivation. They were be used to produce renewable energy in the form of energy sticks of the green charcoal and the charcoal power briquette. The results of this study showed the amount of the energy sticks had directly affects to the heating value and the duration of the fire. The quantities of green charcoal were 1 kg, 2 kg and 3 kg had the heating value were 0.339 kW, 0.611 kW, and 0.985 kW, respectively. The quantities of charcoal power briquette were 1 kg, 2 kg and 3 kg had the heating value were 0.603 kW, 0.753 kW, and 1.005 kW, respectively. And the quantities of normal wood charcoal were 1 kg, 2 kg and 3 kg had the heating value were 0.703 kW, 0.746 kW, and 0.921 kW, respectively. The results of this study also showed that the heating value per unit of the green charcoal, the charcoal power briquette, and the normal wood charcoal were 0.324±0.017 kW/kg, 0.438±0.144 kW/kg, and 0.461±0.212 kW/kg, respectively. The charcoal power briquette and the normal wood charcoal had the duration of the fire were 83.33±25.17 minutes and 90.00±30.00 minutes, respectively while the green charcoal had the duration of the fire was 66.67±12.58 minutes. This study concluded that the green charcoal and the charcoal power briquette that made from the solid waste of the straw mushroom cultivation could be used instead of the normal wood charcoal. Therefore, this study concluded that the energy sticks were produced from the solid wastes of the straw mushroom cultivation that could be used to provide heat energy as well. They should not been wastes, which was useless and waste pollution.

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