Calorific value of dried branches of coconut plant at different moisture contents

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Abstract: The reserves of non-renewable energy sources such as coal, crude oil and natural gas are not limitless, they gradually get exhausted and their price continually increases. In this work, we explored the use of a bomb calorimeter to determine the calorific values of coconut branches as an alternative source of energy. In this work, we explored the use of bomb calorimeter to determine the calorific values of coconut branches as a source of renewable energy. The calorific values of dried coconut branches were determined by using the bomb calorimeter along with the data of moisture content. The calorific values were noticed to be indirectly proportional to the moisture content. The calorific values (kJ kg^{-1}) of the sample as a function of the moisture content is correlated with correlation coefficient (R^2) was 0.96. Ten out of fifteen samples collected were observed to have moisture content in the range of 10% to 30%. With these moisture contents, the amount of calorific values found were in the range of 14-16 MJ kg^{-1} which show its importance and practicality as a source of renewable energy.

Keywords: coconut dried branches, calorific value, moisture content, biomass fuel.

Citation: Basunia, M. A., and M. H. B. H. Zaini. 2022. Calorific value of dried branches of coconut plant at different moisture contents. Agricultural Engineering International: CIGR Journal, 24 (3):103-111.

1 Introduction

Brunei Darussalam has been known for its vast reserves of petroleum and gas, which has fueled the nation's economy for the past 85 years (BSP, 2015). Brunei's current over-reliance on oil and gas as the sole sources of energy to generate income and provide a ready surplus of energy for the citizens of Brunei is not sustainable in the long term without proper energy efficiency and conservation measures. Brunei consumes a disproportionate amount of energy in relation to its small population. The usage of energy consumption for transportation, mainly from fossil fuels, and electricity, mainly from gas, per capita (8672.9 kg of oil equivalent) are among the highest in Asia (REEEP, 2012).

Furthermore, the country has been affected as a result of lowering global oil prices as the economy of the country mainly dependent on oil and gas (World Bank, 2018). According to World Bank (World Bank, 2018) data, Brunei used to have one of the highest Gross Domestic Product (GDP) per capita, 27,466.34 USD (2020) in the world, similar to other oil rich countries such as the United Arab Emirates (38,661.18 USD) and Saudi Arabia (20,110.32 USD). Data shows that there has been a significant drop in GDP per capita in Brunei over the last five years. Therefore, it is a must for the country to diversify its economic resources. Implementing new renewable energy is part of it. Amongst different sources of renewable energy, biomass residues hold special promise due to their inherent capability to store solar energy and amenability to subsequent conversion to convenient solid, liquid and gaseous fuels (REEEP,

Received date: 2021-03-22 **Accepted date:** 2022-05-12

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2012).

Brunei has considerable forest resources, with an average of 382 tonnes of wood potential per hectare across the country (Zaini, 2019). The proper cultivation of rainforest for energy production has been identified as a priority for increasing the utilization of renewable energy sources in the country, provided that an integrated total system design was used to prevent undue damage to the nation's forest resources. In addition, with the increasing population and the six landfill sites, the country should be able to produce landfill gas for power generation as a by-product of the decomposition of solid wastes (REEEP, 2012).

Coconut plant can be one of the sources of biomass energy for this country. The coconut trees are easily grown in Brunei with little or no maintenance. Not only it's a non-seasonal crop, the tree can shed a lot of its branches throughout the year. Coconut trees are long lived (up to 100 fruit years) and are a constant and long-lasting source of economically valuable materials. At present, among the coconut farm wastes such as husks, shell, coir dust and coconut leaves, the latter is considered the most grossly under-utilized by in situ burning in the coconut farm as means of disposal (Banzon, 1980, 1984). As such, it will be beneficial for the country if the wastes can be utilized as a source of biomass energy to augment several percentages of the country's total energies.

The coconut plant has one of the largest leaves of the plant in the world. It averages 6.1 m long and weighs 2.65 kg air-dry (Zuniga et al., 1965). The average number of fallen leaves per hectare is reported as two thousand five hundred seven in a year. Ninety percent of the leaf is the "branch" (petiole) which is often used as fuel for cooking in the villages. The leaf blade constitutes 7%, and the midribs, 2% of the leaf. In one leaf, the petiole weigh is 2.17 kg dry.

A study conducted by Banzon (1980) considered the petiole only to assess the fuel potential of the coconut leaf. He reported that three hundred seventy-seven million coconut trees in Philippine, and each producing at least 12 leaves a year. The energy from these petioles was calculated to be (39 ×1012) kcalories, based on a total of (45 × 108) leaves with a total weight of 4000 kcal/kg (16.7 MJ kg^{-1}).

Harker et al. (1982) reported 791 calorific values for 434 species of 249 genera and gave an average value for all woods as 19.96 MJ kg^{-1}, for hardwood (19.73 MJ/kg), and for softwood 20.82 MJ kg^{-1}.

Lyons et. al. (1985) reported that 90% of observed calorific values of different wood species lie between 18 and 21 MJ kg^{-1}, but the observed spread of calorific values was 15.00 - 25.11 MJ kg^{-1}.

The heating values of biomass fuel can be determined experimentally and can be calculated from the ultimate and/or proximate analysis data (source). Demirbas et.al. (1997) reported that calculation of high heat values (HHVs) from their ultimate and proximate analysis data show mean differences from measured values ranging from 0.1% to 4.0%. Glova et al. (1994) reported the relationship between heating value and chemical composition of selected agricultural and forest biomass. It was reported that, regression model with the ultimate elemental composition as independent variable gave better correlation to measure gross heating value than those based on the proximate chemical composition. Carbon, Hydrogen, Nitrogen, Oxygen and Sulfur are the elements which make up the various components of wood (cellulose, hemicelluloses, lignin etc.). Generally, in wood, the elemental compositions of carbon, oxygen, hydrogen and nitrogen are 45%-50%, 40%-45%, 4.5%-6% and 0.3%-3.5% respectively on dry weight basis, whereas, the percentage of sulphur is negligible (less than 0.1%). Carbon and hydrogen are the main heat producing elements and directly contribute to the heating value of fuel wood (Tillman, 1978).

Khider and Elsaki (2012) reported that ash content in fuelwood is negatively correlated with heating value and Holocellulose having correlation coefficients of -0.756 and -0.676 respectively. The ash amount varies within the tree parts and highest ash concentration is found in tree foliage (shoots and leaves).

There was no study in Brunei about calorific values of dried branches of coconut, and also very limited study were done in other coconut producing countries (Zaini, 2019). Hence, the need of this research work to further investigate the usefulness of dried coconut branches by

determining its calorific value along with its relation with moisture content. This is to prove the practicality of coconut branches as a biomass energy that can be used to sustain the country's development economically and environmentally. So, the objective of this research is to determine and relate the data for the calorific values of coconut branches with its moisture content.

2 Methodology

2.1 Materials

All the coconut branches obtained for this work were sourced locally in Kampung Lamunin, Tutong, Brunei from February to March, 2019. Fifteen fallen dried branches were randomly selected from eight coconut trees. All the coconut trees were of the age 15-20 years old. The number of days the branches had fell from the tree was not known. Some of the branches are shown in Figure1 below.

2.1.1 Sample for dry-oven

The fallen branches were cut as shown in Figures 2 and 3. They were cut into 20 cm from the base of the petiole. The length of the sample was approximately 8 cm. These dimensions were chosen in order to get approximately 50 g of the sample for moisture content determination which is commonly used for agricultural products.

Figure 1 The fallen branches

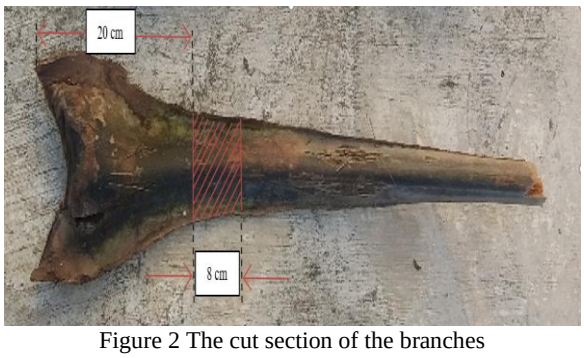

Figure 2 The cut section of the branches

Figure 3 The sample for oven-drying

Once cut, the samples were put into polyethylene zip bags and stored in a desiccator in order not to make them susceptible to the surrounding moisture in the air which could change the moisture content of the sample.

2.1.2. Sample for bomb calorimeter

The samples needed for the combustion in calorimeter need to be very small like the size of a sawdust which is ranging from 2.5 to 10 μm. To obtain this size, coarse wood files/rasp was used. The coarse samples were then stored inside a double layer polyethylene bag and stored in refrigerator for uniform moisture content.

2.2 Moisture content

The sample was kept for more than 24 hours inside the polyethylene bag. The sample was then placed inside the oven and dried at a temperature of 105℃ and left overnight. The mass of the test sample was determined and oven dried again for 1 hour. This mass was recorded as the "oven dry mass".

The moisture content was calculated by using the wet- and dry-basis formulae:

Moisture content on wet-basis,

$$M_{\mathrm{wb}}=\left(\frac{W_w}{W_w+W_d}\right)\times 100 \quad (1)$$

Moisture content on dry-basis,

$$M_{db}=\left(\frac{W_w}{W_d}\right)\times 100 \quad (2)$$

where, M_{wb} is the moisture content in wet-basis (%), M_{db} is the moisture content in dry-basis (%), W_d is the dry matter weight of sample in gram and W_w is the weight of the water in the sample in gram.

2.3 Calorific values

The calorific values were determined by using the

bomb calorimeter (Temperature resolution 0.001, Repeatability error ≤ 0.2%) in the Laboratory of Mechanical Engineering Programme Area (MEPE), Faculty of Engineering, Universiti Technology Brunei (UTB), Brunei Darussalam. The calorimeter is called as oxygen bomb calorimeters, which is the standard instruments for measuring calorific values of solid and liquid combustible samples. To stay within safe limits, the bomb was never charged with a sample which would release more than 8000 calories or 10,000 calories when burned in oxygen and the initial oxygen pressure was never exceed 40 atmospheres (590 psig). This generally limits the mass of the combustible charge (benzoic acid or any combustion aid) to not more than 1.1 grams. Bomb calorimeter was a type of constant-volume calorimeter and it was used in measuring the heat of combustion of samples which can be burned in oxygen. There are four essential parts in the bomb calorimeter (Figure 4). A bomb or vessel in which the combustible charges was burned, a bucket or container for holding the bomb in a measured quantity of water, together with a stirring mechanism, an insulating jacket to protect the bucket from transient thermal stresses during the combustion process, and a thermometer for measuring temperature changes within the bucket.

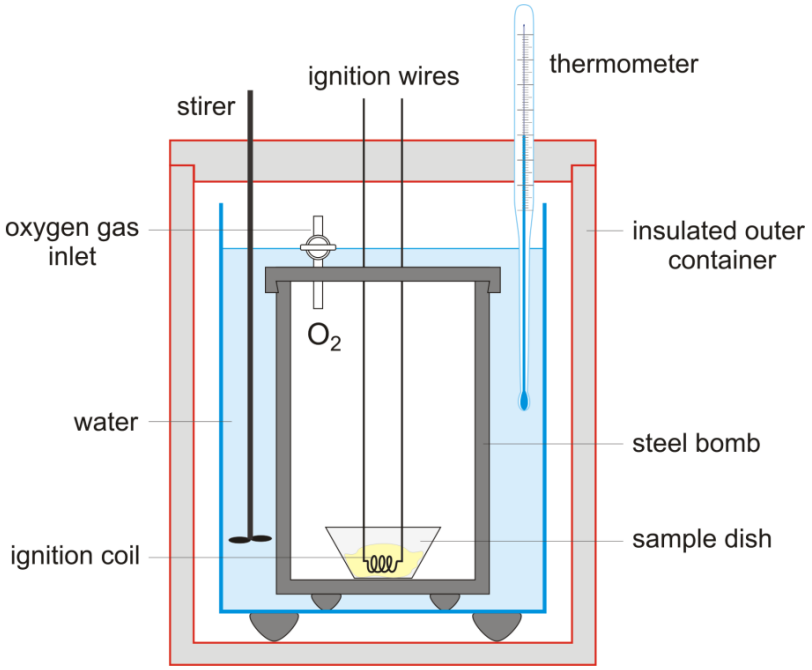

Figure 4 Bomb calorimeter

2.3.1 Calculation for calorific values

The calorific value was calculated by the following equation

$$CV = \frac{Q_w + Q_b}{m_s} = \frac{C_{pw} m_w \Delta T}{m_s} \quad (3)$$

where, CV is the calorific value (J g^{-1}), Q_w is the heat absorbed by the water (J), Q_b is the heat absorbed by the bomb calorimeter (J), C_{pw} is the specific heat capacity of water (J g^{-1}°C^{-1}), C_b is the heat capacity of bomb calorimeter (J °C^{-1}), m_w is the mass of water (g), m_s is the mass of sample and (g) and ΔT is the change in temperature (°C).

2.3.2 Heat capacity of the bomb calorimeter

A bomb calorimeter (calibrated using benzoic acid tablets) was used to determine the energy contained in the samples by quantifying the heat generated during its combustion. Any heat exchange between the bomb calorimeter and the external environment was prevented by insulation. In order to find the calorific values of a sample, first the heat capacity of the bomb. calorimeter was determined. The same procedures of bomb calorimeter were used but by using a known calorific value substance. In this case, benzoic acid was used. The calorific value of benzoic acid was 26,465 J g^{-1}, mass of benzoic acid, and the change in temperature taken during the experiment was 2.9℃. The calorimeter bucket was filled with 2000 grams of distilled water of temperature between 24 and 27 ℃. Water dropper was used to obtain

an accurate measurement for the last 5 grams of water. Water was made certain not to spilled or added to the calorimeter bucket and that all the water droplets were removed from the outside of the calorimeter bucket. The temperature rise was recorded every 15 seconds. A graph of the temperature data against time is shown in Figure 5. After the rapid rise period (4 minutes after ignition) the temperatures were recorded at one-minute interval until the difference between successive readings had been constant for 5 times.

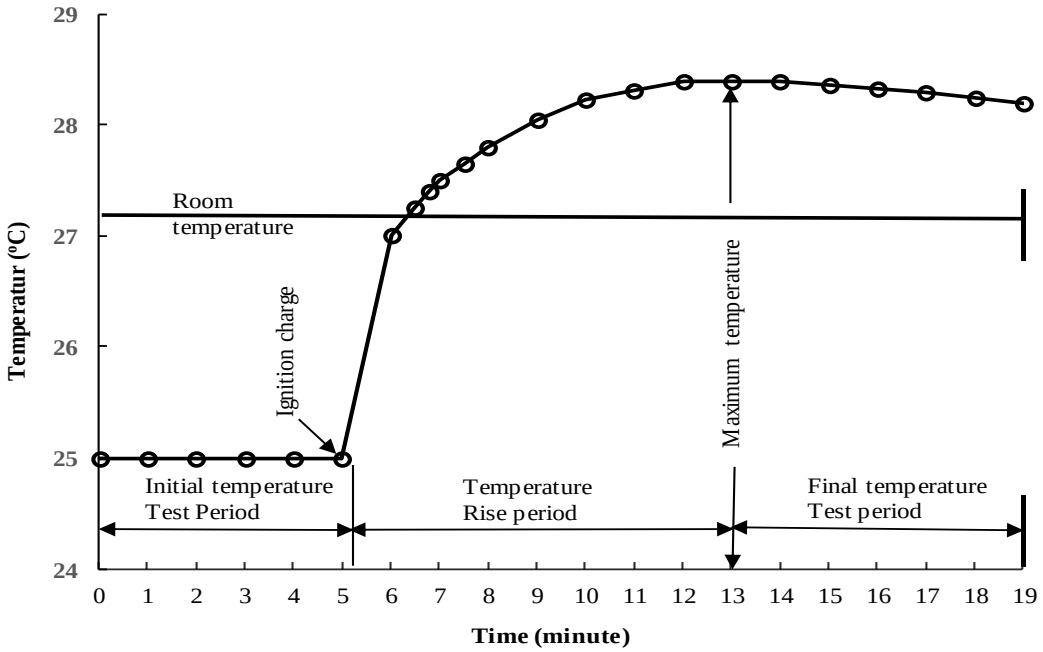

Figure 5 Typical temperature rise for bomb calorimeter

From Equation 3,

$$C_b = \frac{CV\ m_s - C_{pw}\ m_w\ \Delta T}{\Delta T}$$

$$C_b = \frac{26465\left(J/g\right)\times 1\,g - 4.184\left(\frac{J}{g^oC}\right)\times 1980\ g\times 2.9^oC}{2.9^oC}$$

C_b = 893.4 (J $^oC^{-1}$)

Therefore, the heat capacity of the bomb was 893.4 J $℃^{-1}$.

2.3.3 Test with samples

The calorimeter bucket was filled with 2000 grams of distilled water of temperature between 24 ℃ and 27 ℃. An approximately 10 cm length of fuse wire was cut and attached to the bomb head through the eyelet holes. A cotton thread was tied in the middle of the fuse wire and was let hanged. The sample was then put inside the crucible and weighed using electrical balance to 0.6 grams. The cotton thread was let to touch the top of the sample and was made certain that the cotton thread did not touch any part of the crucible. The bomb head was carefully removed from the stand and placed in the cylinder. It was then carefully pushed straight down the cylinder until the O-ring was below the top surface. The screw cap was placed on the cylinder and turned tight. Next step was bomb charging. Thumb screw connector was attached (female threads) from the oxygen filling unit onto the check valve on the bomb head (the valve with the male threads). The main oxygen valve was turned on fully open (the one directly connected to tank - not the one on the regulator). The relief valve lever was made sure to be horizontal. The regulator valve was then opened to not more than one-fourth to slowly fill the bomb. When the pressure reached 30 atm, the valve was turned off on the regulator.

The oxygen filling connection from the bomb head was then unscrewed. The hex screw was carefully loosened to release the bomb from the clamp. The bomb was finally inserted into the calorimeter bucket and placed above the circular indentation on the bottom of the bucket. The calorimeter cover was put down over the bomb and ensured that the connector button was pressed down. The digital thermometer was then put into the calorimeter bucket. Before starting a measured run, the stirrer was let to run until the 'ready' indicator lights on to indicate that it had finally reach equilibrium. The

initial temperature was then recorded at this point. The 'fire' button was pressed and held for approximately 5 seconds to fire the bomb. To know whether the fuse wire was burned or not, the 'test' button was immediately pressed after pressing the 'fire' button. If the 'test' button did not light up, this indicated that the fuse wire was burned. The water bucket temperature was then recorded every 15 seconds. Same procedures were applied for each sample.

3 Results and discussions

The total samples were 15, however only nine samples were selected in this result section as most of the samples had the same amount of moisture content. Table 1 represents the results of drying process to obtain the moisture content.

The rise of temperatures of all the samples were in the range of 0.7℃ to 1.1℃. Figures 6 and 7, show the temperature rise against time of combustion of sample A and sample I, respectively inside the bomb calorimeter. The temperature raising rate was slightly higher with the reduction of moisture content (Figure 7). Similar trends of temperature profiles were also observed with the remaining samples.

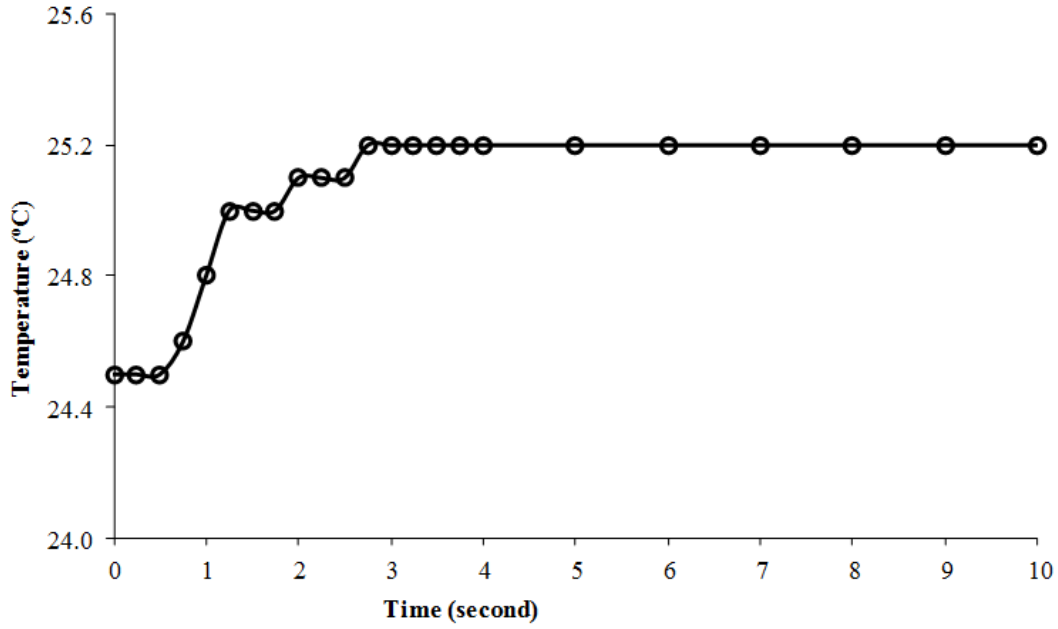

Figure 6 Temperature rise of sample A in the bomb calorimeter

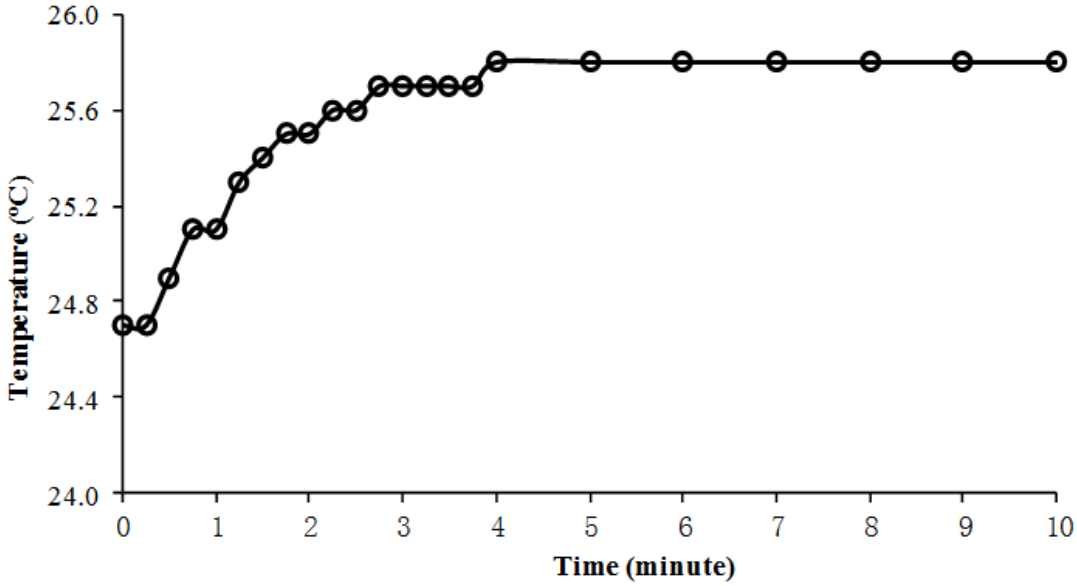

Figure 7 Temperature rise of sample I in the bomb calorimeter

Table 2 below shows the time for the sample to raise 0.5℃. With the temperature difference obtained, calorific value was calculated and shown in Table 2.

Table 1 Mass of sample, comparison between dry-and wet-basis moisture content

Sample	Initial mass, W_i (g)	Oven-dry mass, W_d (g)	Weight of the water, W_w (g)	Moisture content (dry basis) (%)	Moisture content (wet basis) (%)
A	63.53	28.89	34.64	119.9	54.52
B	51.37	25.46	25.91	101.8	50.44
C	41.83	21.76	20.07	92.2	47.98
D	40.02	25.56	14.46	56.6	36.13
E	36.67	24.43	12.24	50.1	33.38
F	33.83	25.90	7.93	30.6	23.44
G	32.38	27.30	5.08	18.6	15.69
H	25.91	22.45	3.46	15.4	13.35
I	19.83	17.81	2.02	11.3	10.19

Table 2 Time taken to raise the temperature by 0.5°C and calorific values

Sample	Moisture content (dry basis) (%)	Moisture content (wet basis) (%)	Time taken to raise temperature by 0.5 ℃ (s)	Temperature difference (℃)	Calorific value (MJ kg^{-1})
A	119.9	54.52	105	0.7	11.15
B	101.8	50.44	105	0.7	11.15
C	92.2	47.98	90	0.8	12.53
D	56.6	36.13	75	0.8	12.53
E	50.1	33.38	90	0.8	12.53
F	30.6	23.44	75	0.9	13.91
G	18.6	15.69	75	1.0	15.29
H	15.4	13.35	75	1.0	15.29
I	11.3	10.19	68	1.1	16.68

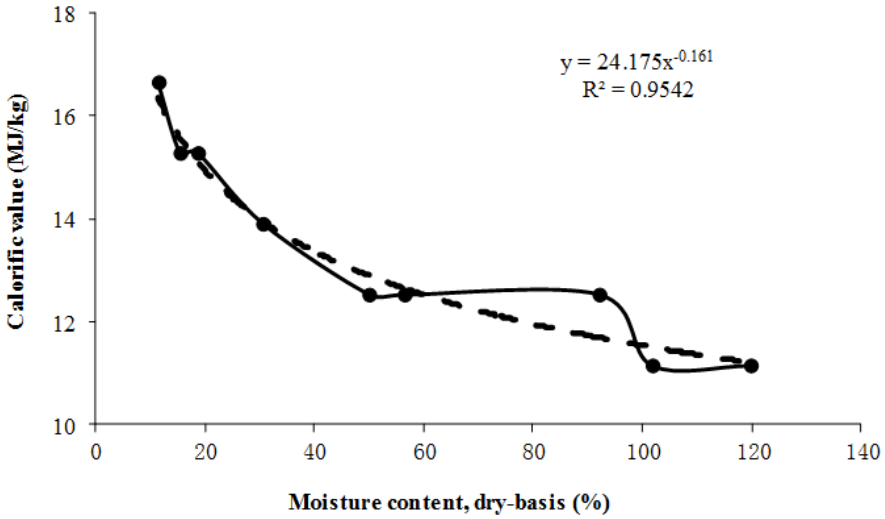

Figure 8 Variations of calorific values with moisture contents (Dry-basis)

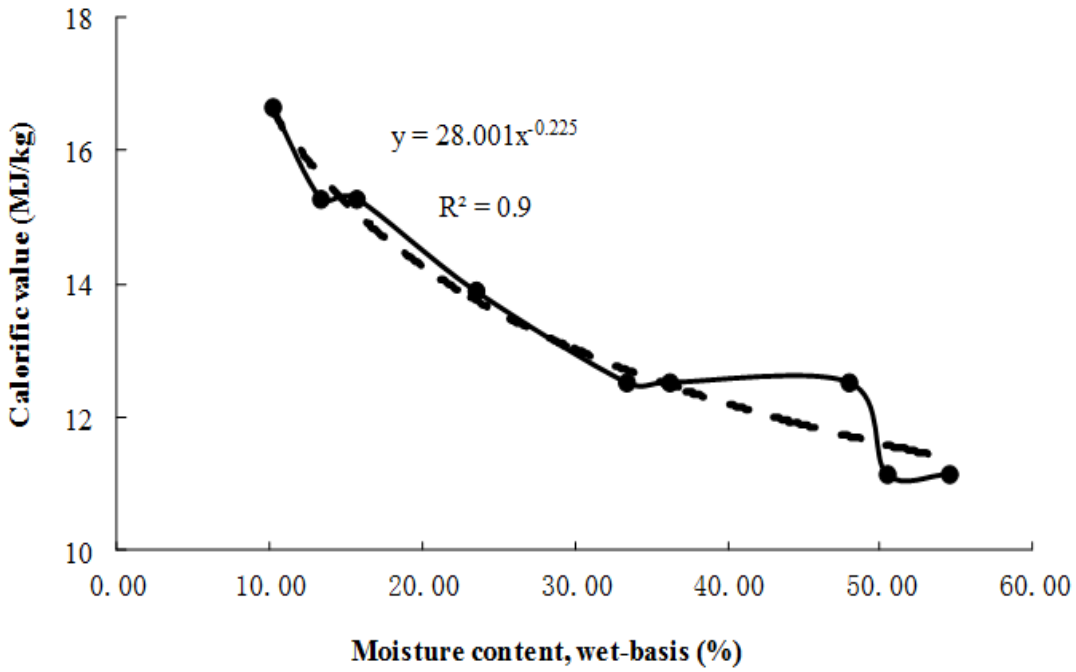

Figure 9 Variations of calorific values with moisture contents (Wet-basis)

Figures 8 and 9 represents the relationship between the moisture contents and the calorific values of the samples in dry- and wet-basis, respectively.

From the graph of the calorific value against moisture content, it was shown that the graph with the wet base moisture content had a higher coefficient of determination (R^2) of 0.96 which showed that it had a smaller difference between the observed data and the fitted values. As such, only the moisture content of wet-basis value has been discussed in this section.

The data for the firing period of the samples showed that it took a short period of time (15-30s) for the water temperature to rise from its pre-firing value. This was because heat was immediately released during the combustion, thereby attesting that it was indeed an exothermic reaction.

All of the combustion during firing the bomb calorimeter burned all the samples showing the test was successful and gave assurance to the data obtained. Formation of liquid water (condensate) was also noticed in the interior walls of the bomb calorimeter, proving that combustion of the samples really produces water in the liquid form.

From the nine samples tested in this study, the moisture content of the samples were found to be in the range of 10.19% – 54.52% (Zaini, 2019). The time taken for each of the samples to raise its temperature by 0.5℃ was indirectly proportional to the moisture content. It took 68 seconds for the sample with the lowest moisture content and 105 seconds for sample with the highest moisture content.

This is also true for the relation between moisture content and calorific values. As shown in the graphs (Figures 8 and 9), as the moisture content is higher, the calorific value becomes lower. The highest calorific value was recorded when the moisture content was at 10.19% with a value of 16.7 MJ kg^{-1}. This value is almost comparable with wood pellet of 10% moisture content (Zaini, 2019) The CV lowers down to about 15.0 MJ kg^{-1} for moisture content of 13%-15% and even lower to about 14.0 MJ kg^{-1} when it reached 20%. However, this was still considerably higher if compared to wood chips of 30% moisture content which only had 12.5 MJ kg^{-1}. The samples with 30%-50% of moisture contents had a noticeably low calorific values of 11 to 12 MJ kg^{-1}.

As stated earlier, a farm of coconut tree had approximately 2507 fallen branches per hectare per year with each dried branch had a mass of 2.17 kg on average. Table 3 below shows the total amount of energy per hectare per year of a coconut farm.

Table 3 The energy of a coconut farm per hectare per year

Moisture content of coconut branches (%)	Average calorific value (kJ kg^{-1})	Calorific value per branch of 2.17 kg (kJ)	Calorific value of 2507 branches per hectare per year (MJ)	Calorific value for 1000 hectares of coconut farm per year ($\times 10^7$ MJ)
10-20	15295	33190	83207	8.321
20-30	13224	28696	71941	7.194
30-50	11844	25701	64432	6.443

With this calculation, it can be estimated that a coconut farm can produce energy of between 64432 to 83207 MJ per hectare per year; enough to be considered as a good source of renewable energy for a small power station. With just one hectare of a coconut farm, it can produce up to 83200 MJ per year. If one house uses 16000 kWh, the number of houses a thousand hectare of coconut farm can sustain would be approximately 1400 houses.

4 Conclusions

Fuel value of biomass is greatly dependent on its heating value and is generally believed to be one of the parameters to characterize fuel. It can be concluded that the moisture content greatly affects the calorific value of a substance. The calorific value (CV, MJ/kg)) of the sample as a function of the moisture content was correlated using the following equation: $CV = 28.001 \times (M_{wb})^{-0.225}$ ($R^2 = 0.96$). Most of the fallen branches collected had moisture contents within 10%-30% and had calorific values of 14-16 MJ kg^{-1}. This amount of calorific value is enough to support the idea of the practicality of it being used as a good source of renewable energy.

Acknowledgement

The authors are very grateful to UTB for their partial financial support and allowing us to use the lab facilities of Mechanical Engineering Programme Area of UTB.

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