Techno-Science Research Journal 8 (2020) 84-91

Content list available at ITC

Techno-Science Research Journal

Journal Homepage: www.ric.itc.edu.kh

Techno-Science
Research
Journal

Experimental Investigation on Sawdust and Tree Leaf Briquette Ratio Using Fish Residues Oil as a Binder

Latin Heang, Porchaing Choeng, Kinnaleth Vongchanh*, Sarin Chan

Thermal lab., Department of Industrial and Mechanical Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia

Received: 29 June 2020; Accepted: 14 November 2020; Available online: xxxx

Abstract: *Increasing waste disposal and energy demand are a problem in the city today. Densification of biomass waste from sawdust and tree leaves into solid fuel briquette not only reduces waste reduction but can also be an alternative source. Raw materials and binders are two essential variables, among other important variables, presented in this article. Fish oil extracted from fish residues is a combustible binder with a high heating value. Investigations and experiments on the various mixing ratios between the tree leaves-sawdust, by keeping a constant amount of binder at 10% in mass of 4 kg from the tree leaves and sawdust to produce briquettes using screw press briquette machine, and the properties of each mixture are the goals in this work. In this study, eleven compositions of tree leave and sawdust from 0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10, 100:0 were investigated. The properties of the briquette included the values of density, impact resistance, water resistance, heating value, burning rate, energy density, moisture content, volatile matter, ash content, and fixed carbon, were evaluated. The experimental results showed that the average energy density of briquette is 6 times and 16 times greater than raw sawdust and tree leaves, respectively. Tree leaves and sawdust briquette with a mixing ratio of 30:70 had the highest heating value (22.15 MJ/kg), density (1.127 g/cm^3), fixed carbon (20.18%), Volatile (76.52%), and low ash content (3.29%), and burning rate (0.93 kg/h). The results indicated that heating values and proximate analysis were not much different within the five samples. Besides that, water resistance tests were uncertified at a higher ratio of tree leaves.*

Keywords: Biomass properties; Briquette; Fish oil; Sawdust; Solid fuel, Screw press machine; Tree leaves

1. INTRODUCTION

The tree is the plant that absorbs CO$_2$ emission, provides shade and fresh air for life's beautiful landscape. At the same time, many trees are turned to be furniture of local products and export. The waste from the process of making furniture is the sawdust which recently is the city waste. Besides that, dried/fallen tree leaves become the city waste.

Every year, 4.3 million tons of primary wood demand is required for wooden material supplies such as furniture and home building in Cambodia (Joya, 2014). Through this process, approximately 2.9 km^3 with an energy density of 8.4 GJ/m^3 of sawdust are produced every year (Tun et al., 2019). Regarding the actual daily record of the sawdust production per week is 300 kg on average, recorded information in a wooden furniture workshop in Phnom Penh. while a large number of dried tree leaves felt around 400 kg per week in the dry season, recorded information in the Institute of Technology of Cambodia. These wasted dried lives were daily collected and sent to landfills or sometimes these dried tree leaves are burned; which becomes waste heat. Labour is paid for collecting the leaves which do not produce any income. Wood and tree residues are considered the major source of biomass in rural communities which can sustainably contribute towards meeting the energy demand of rural people for direct heat applications through the production of biomass briquette (Obi, 2015). Besides, in Cambodia freshwater fish provide up to 79% of all animal protein intake where around 300000 to 600000 tonnes each year (Baran et al., 2014). Due to this large demand, it leaves a fat content of about 9 to 14% of its total mass (Puwastien et al., 1999). For hard material like sawdust require additional binder in the densification process (Tabasso et al., 2020), so fish oil is a combustible material and is a daily waste in the city while it is a sticky and combustible material with low ash which was a good quality to be used as the binder in briquetting process.

In recent years, researchers were attempted to find the possibilities of applying biomass materials such as sawdust, and tree leaves using oil as a binder to be a renewable source for producing biomass briquette.

---

[*] Corresponding author: Kinnaleth Vongchanh
E-mail: kinnalethv@yahoo.co.uk; Tel: +855-99-351-199

Chin et al. (2000) have experimentally investigated the characteristics of different biomass materials (sawdust, rice husk, peanut shells, coconut fibers, and palm fruit fibers) which were densified into briquette using starch and molasses as the binders under different die pressures. The result shows that sawdust briquette has better overall handling characteristics than others.

Rajaseenivassan et al. (2016) investigated the possibility of using neem powder as a binder of sawdust by changing the ratio of sawdust: Neem powder (100:0, 75:25, 50:50, 25:75, 0:100). Briquettes were produced by using a manual operation hydraulic pelletizer in a pressure range of 7-33MPa. As a result, neem powder can be used as binding material with sawdust by increasing physical properties (shatter index, impact resistance, water resistance, and durability) but lower combustion properties (burning rate and heating value). Obi (2015) prepared the briquettes from sawdust waste at moisture 8.15% with palm oil mill as binder using 20t hydraulic jack. with palm oil mill sludge (10, 20, 30, 40, 50, 60, 70, 80, 90, 100) % of the weight of the compacted sawdust. Results revealed that increasing binder amounts can increase physical and combustion properties.

Inthavideth et al. (2017) have investigated properties of briquette from a composition of sugarcane, tree leaves, paper, and rice husk. The briquettes densification process was manually carried out using the hydraulic press of mixing ratio 1:1 (by weight) with cassava flour as a binder. The result shows that the compositions of tree leaves: rice husk: cassava: water (700:700:630:1800 g) has the highest density (0.58 g/cm^3), heating value (15.35 MJ/kg), and moisture content over 12% after dried 14 days, all briquettes flame temperature was in the range of 617°C and 795°C.

Suprianto and EVANDER (2017) investigated on leaves waste (Pterocarpus Indicus) briquette having tapioca as a binder by compress under pressure 2Mpa. The composition ratio was selected from 50:50 to 90:10 of leaves waste and tapioca respectively by rising by 10% for each experiment. The particle size of the leaves was 60 Mesh (0.25mm). The result showed that 100% of Pterocarpus indicus has calorific value1.37 times higher than 100% of tapioca. Therefore, the composition of 90% leaves waste and 10% of binders produce the highest calorific value of biomass briquette.

Deepak and Jnanesh (2016) investigated various characteristics of coconut leaves (size 850μm) with sawdust powder (additive) and wheat flour (binder) at a ratio of 2:1:1 respectively for making briquette. Testing was conducted using a single piston and ram type briquetting machine. The results showed that the briquettes produced from coconut leaves with sawdust as an additive and wheat flour as a binder would make good biomass fuels. It has been concluded that the production of briquettes from leaf briquettes are cheaper and feasible.

Choeng et al. (2018) investigated the effect of boiling time, and the level of fish residues as a binder of rice husk and sawdust briquette's properties by using a hydraulic press machine with mold temperature 130°C. The boiling time of oil was changed from 30 to 45 mins while fish residues changed from 500 to 700g with a constant ratio of rice husk and sawdust at 1:1. The result indicated that average MC, heating value and density were 18.36MJ/kg, 6.3%, 1135.7 kg/m^3, respectively. The calorific value was highly dependent on the moisture content wet basis. The moisture content of the briquette depended on boiling time and quantity of fish residues; when the number of fish residues was higher quality then the MC of briquettes was also higher; The maximum heating value was 21.7 MJ/kg under fish residues 500g and boiling time 45 mins.

Choeng et al. (2019) have investigated the effect of fish oil as a binder at 5%, 10%, 15%, 20%, and 25% of mixing mass raw materials (sawdust and rice husk at ratio 1:1) by using screw extrude briquette machine. The experimental result provides that fish oil can be used as a good binder of briquette from rice husk and sawdust. And the optimization level of binder suitable for rice husk and sawdust briquette was found as 10%.

The literature shows the importance of biomass energy in today's situation. In previous works, the researchers made investigations to improve the performance of the briquette by varying the applied pressure, different binding materials. Using oil as the binder can improve combustion rate, low ash, and also being lubricant material in the system which leads to an increase in the lifetime of the machine. The literature shows that strength is a very important parameter in handling, transportation, and stable combustion of biomass briquettes.

Therefore, the purpose of this study is to investigate the use of fish oil (FO) as a binder for producing combined sawdust and tree leaves briquette using a screw press machine. To produce briquettes having fish oil as a binder, investigation of the most suitable composition was carried out by examining the properties including density, water resistance index, impact resistance index, moisture content, burning rate, heating value, and proximately analysis.

2. METHODOLOGY

2.1 Raw material

The sawdust (SD) used in this study was collected from a wooden furniture workshop in Phnom Penh, while dried tree-leaves (DT) were obtained from the campus of the Institute of Technology of Cambodia.

The freshwater fish residues (the fat and intestine) were obtained from the local market in Phnom Penh.

2.2 Material preparation

The initial moisture content of raw tree leaves was 9.43% and sawdust was 10.28% (wet basis), analysis using the oven-dry method at 105°C. Sawdust was sieved to remove big wood chips by keeping particle size that less than 8mm. Dried tree leaves were crushed to a small piece that less than 8mm.

Eleven compositions of vary DT & SD were combined with 10% of fish oil (FO) were investigated in this study. The composition of tree leaves and sawdust were thoroughly mixed at a ratio of 0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10, and 100:0 and denoted by the manuscript as A, B, C, D, E, F, G, H, I, J, and K respectively

2.3 Briquetting operation

Fig.1. Briquetting process

Firstly, tree leaves and sawdust were weighted and mixed follow the composition ratio of A, B, C, D, E, F, G, H, I, J, and K using mixer motor for 3 mins, then fish oil for 10% was added through the compound of raw materials by continue mixing for 5 mins more until the binder and raw materials were homogenous. Secondly, start the heater that wraps up on the mold of the screw press machine for 15 mins to 20 mins, until mold temperature constant at 300℃. Then composite materials were brought to the place in the hopper of the screw press machine and start operation. Finally, if production were not formed as briquette or it had a lot of cracks on its surface, it was counted as failed to produce for that ratio. The briquetting process is shown in Fig.1.

2.4 Briquette density

The density for each composite briquette composition was determined after produce one week and was calculated from the ratio of mass to the volume of briquette (ASTM D 2395). The mass of briquette from each sample was obtained by using a digital balance with precision 0.5g, while the volume was calculated by taking the linear dimension (length, edge, hole diameter) of the briquette. The density of briquette was calculated as (Eq.1)

$$\rho = m / V \qquad \text{(Eq.1)}$$

Where:
ρ = density of briquette (g/cm^3)
m = mass of briquette (g)
V = volume of briquette (cm^3)

2.5 Impact resistance index (IRI)

The impact resistance test is considered to be the best general diagnostic of briquette strength. A practical performance target for impact resistance of a fuel briquette has been counted as the number of falls from an initial position at a height of 2m onto a concrete floor. This test contains averaging the results of 5 single drop tests. Each briquette was repeatedly dropped until it fractures, piece of mass that greater than 5% of the initial mass was counted (Mitchual et al., 2014). The number of drops and the number of pieces of briquette was recorded. Then IRI was calculated using (Eq.2) An IRI value of 50% has been adopted as being the lowest acceptable impact resistance for fuel briquettes being developed for industrial (Richards, 1990).

$$\text{IRI} = (\text{AND} / \text{ANP}) \times 100 \qquad \text{(Eq.2)}$$

Where:
IRI = impact resistance index
AND = average number of drops
ANP = average number of pieces

2.6 Water resistance index (WRI)

The Water-resistance test is used to evaluate the resistance of briquette against water absorption and disintegration. A weighted briquette was immersed in cold tap-water at room temperature 30°C and check for any tendency to disintegrate by applying finger pressure at 10 mins interval. If briquette can survive 30 mins, then wipe to remove moisture surface and reweight. The results have been reported separately in descriptive terms of tendency and time to disintegrate and percent absorption. Then WRI was calculated using (Eq.3). A value of 95 for WRI would be a reasonable target for most briquette types that maintain integrity after 30-minute immersion (Richards, 1990).

$$\text{WRI} = 100 - \%\text{Water absorption} \qquad \text{(Eq.3)}$$

2.7 Moisture content (MC)

Moisture content is the amount of water that is contained in the briquette, eliminated by drying at 105℃. Briquette samples were cut to have 3 pieces weighed 5g to 10g each then put in the aluminum disk, the initial mass of briquette piece and disk were recorded. Samples were dried in the oven at 105 ℃ for haft day or 6 hours later on let samples cool in desiccators for 20 mins before record its mass, repeat drying 3 hours until the difference between two consecutive measure is less than ±0.2%, then stop drying, and calculate moisture content follow equation (Eq.4). If the difference is over ±0.2%, continue drying 3 hours more until mass different less than ±0.2%

$$\%MC = (m0 - mn+1)/m_0 \times 100 \quad \text{(Eq.4)}$$

Where:
m_0 = mass of the initial sample (g)
m_n = mass of the sample after drying number n (g)
m_{n+1} = mass of wood after drying number n+1 (g)

2.8 Heating value (HV)

The heating value or calorific value is the amount of heat released with the complete oxidation of fuel without taking into consideration the condensation heat of the water vapor present in the smoke (Döring, 2013). The calorific value was determined by using Oxygen Bomb Calorimeter 1341 at room temperature between 25°C and 28°C. Oxygen bomb was used to place the sample at 1.5g and Oxygen pressure 30atm. After that, place it in 2000g (±5g) of distilled water that temperature below 1°C to 2°C of room temperature and check for gas bubbles leakage that may cause the explosion of the equipment. Then, connect the oxygen bomb to the calorimetric ignited electrode and operate for 15 mins. Mass of sample, fuse remain afterburn are required to input in the system final result of gross Calorific value (wet basis) will be given by the calorimeter. To compare samples with different moisture content heating value dry basis was calculated using (Eq.5)

$$HVdry = MC(100/(100 - HVwet)) \quad \text{(Eq.5)}$$

Where:
HVdry = heating value dry basis (MJ/kg)
MC = moisture content (%)

2.9 Proximate analysis

Volatile matter (VM): The volatile matter of a fuel is the condensable and noncondensable vapor released when the fuel is heated (Basu, 2018). The samples were required to break into powder to get only size less than 200µm (10g) and three porcelain crucibles with lip were used to validate error and each crucible fill with 1g of mass sample and dry in a muffle furnace at 900°C for 7 mins as stated in standard CEN 15148 (2005). This procedure was undertaken out of contact with air under standardized conditions. The initial mass of fuel after dry in the oven at 105℃ for 6 hours and mass after dry at 7 min at 900℃ was measure using a high precision digital balance with precision 0.0001g. The percentage of volatility was calculate using (Eq.6).

$$\%Volatile = (m_3 - m_5) / (m_3 - m_1) \times 100 \quad \text{(Eq.6)}$$

Where:
m_1 = mass of the crucible (g)
m_3 = mass of the crucible with dry briquette (g)
m_5 = mass of the crucible with briquette after heated at 900℃ (g)

Ash content (AC): Ash is the inorganic solid residue left after the fuel is completely burned (Basu, 2018). Its primary ingredients are silica, aluminum, iron, and calcium; small amounts of magnesium, titanium, sodium, and potassium may also be present. The ash content of solid fuels affects both the emission of pollutants and the technical design and construction of the combustion plant. To define ash content, samples are required to grind to be powder with particle size less than 200µm and weigh accurately 2g in a porcelain crucible with a lid. Heat to 550°C for 2 hours in an electric muffle furnace. The difference between the initial weight and weight of the sample after combustion will be expressed as a percentage of the initial weight and represents the ash content. A correction can be made for moisture content to express ash on a moisture-free basis.

$$\%Ash = (m_4 - m_1) / (m_3 - m_1) \times 100 \quad \text{(Eq.7)}$$

Where:
m_1 = mass of crucible (g)
m_3 = mass of crucible with dry briquette (g)
m_4 = mass crucible with ash after burning at 550℃ (g)

Fixed carbon determination (FC): This represents the solid carbon in the biomass that remains in the char in the pyrolysis process after devolatilization (Basu, 2018). Fixed carbon was calculated using equation (Eq.8)

$$FC (\%) = 100 - (Ash + Volatile) \quad \text{(Eq.8)}$$

2.10 Energy density (ED)

Energy density is the energy per unit volume of fuel. energy density is a useful measure of the energy that will be released from a given weight or volume of fuel when it is burned. The specific energy and energy density of fuel provide practical measures of the energy content of fuel in units more commonly used in the storage and handling of these substances (energy per weight and volume). From the relation of energy density and specific energy, energy density was determined by using (Eq.9).

$$E_d = \rho \times Es \quad \text{(Eq.9)}$$

Where:
Ed = energy density (MJ/m^3)

ρ = density (kg/m^3)
Es = specific energy or heating value (MJ/kg)

2.11 Burning rate (BR):

The burning is used to determines the rate at which a certain mass of fuel is combusted in the air (Davies et al., 2013). Briquette burning rate was determined according to the method used by Islam et al. (2014). 2 kg of briquettes from each blend were prepared. Samples were weighted in the hearth of different household stoves and stoves were ignited at the same time. This was continued for two hours. After that, the amount of unburned fuel was recorded. Time was recorded with a stopwatch and the mass of briquette was recorded by using a digital balance with 0.01g precision. The burning rate was calculated using (Eq.10).

$$B_R = (Q_1 - Q_2)/T \qquad \text{(Eq.10)}$$

Where:
B_R = burning rate (kg/h)
Q_1 = initial weight of briquette (kg)
Q_2 = final weight of briquette (kg)
T = total burning time (h)

3. RESULTS AND DISCUSSION

3.1 Briquetting

According to experimental results, it was found that the densification process of mixing ratio DT:SD of 60:40, 70:30, 80:20, 90:10, and 100:0 failed to form into briquette shape, the products were cracked and broken into pieces after extruding from the mold which was uncertified for storage and transportation. Besides for briquette at a ratio of 0:100 the resulting operation failed by getting stuck inside the screw press machine, as shown in Fig.2 (a) and (c), respectively. However, briquettes shape was obtained in very satisfying shape for the mixing ratio DT:SD of 10:90, 20:80, 30:70, 40:60, and 50:50 as depicted in Fig.2. (b) Regarding observation, the bulk density of tree leaves (0.077 kg/cm^3) was too low compare to sawdust (0.191g/cm^3) resulting in the bulk density of sawdust and tree leaves combinations lower when the ratio of tree leaves greater than 60%.

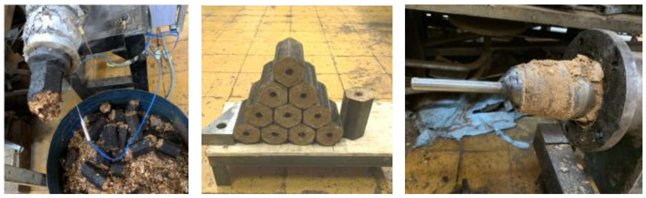

Fig.2. (a) Unshape production, (b) Certified briquettes, (c) Operation failed

3.2 Physical properties of briquette

In this study, the evaluation of physical properties was measured through the density, impact resistance, and water resistance of the composite briquette.

Based on the measured results of density value for different samples including B (10:90), C (20:80), D (30:70), E (40:60), and F (50:50), the density of the briquette was affected by the composition ratio of tree leaves and sawdust. Figure 5 indicated that the density of briquette decreased as the ratio of tree leaves increase. Density ranges from 0.89 g/cm^3 to 1.18 g/cm^3. The experimental result indicated that briquette B (1.18 g/cm^3), C (1.138 g/cm^3), and D (1.127 g/cm^3) are almost the same density value which is acceptable following standard DIN51731 define the interval of briquette density value from 1 g/cm^3 to 1.4 g/cm^3. While E (0.977 g/cm^3) and F (0.895 g/cm^3) were lower than the satisfactory standard. Because of bulk density of tree leaves is (0.077 g/cm^3) lower than sawdust (0.191 g/cm^3), after briquetting at a higher ratio of sawdust becomes more compact than tree leaves.

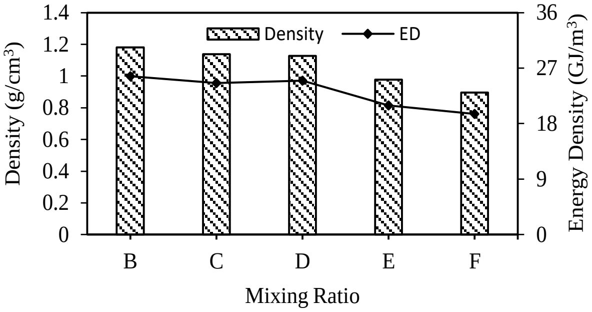

Fig.3. Density and energy density of various mixing ratio of tree leaves and sawdust with fish oil 10%.

Energy density is the amount of energy contains in comparison to its volume. After raw materials of sawdust and tree leave with fish oil as a binder were densified into briquette, its energy density also increased up to 5 and 13 times respectively. Where the average energy density of this five-composition ratio was 21.92 GJ/m^3.

IRI and WRI were tested following Rechard (1990), the obtained results showed that sample B, C, and D passed the qualification; the 3 samples of B, C, and D were very the same value of WRI and IRI of around 500% and 97% for WRI and IRI, respectively. The maximum value of IRI and WRI were given by sample B. According to the results illustrated in Fig.4, sample E showed a different tendency from other samples due to the randomly selected samples. Sample E had a smaller density compared to briquette F, which makes it less compact compared to other, leading to higher water absorption than briquette F. Regarding the observation of the sample, the randomly selected from briquette E, samples have a smaller density compared to briquette F, which makes it less compact compare to other, leading to higher water absorption than briquette F. Besides, it was observed that briquettes with tree leave of more than 40% were less dense, although it was possible to produce solid briquette with a uniform shape and size, which made it more brittle compared to other three compositions ratio.

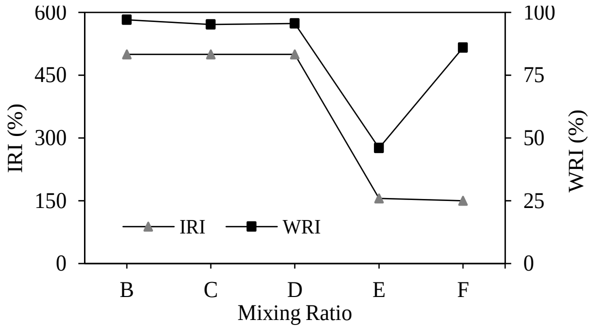

Fig.4. Impact resistance and water resistance index of the various mixing ratio of tree leaves and sawdust with fish oil 10%.

3.4 Combustion properties

Burning rate (BR) test and calorific or heating value (HV) were experimentally obtained from samples B, C, D, E, and F. The BR test was conducted in an open-air room. The result indicated that when the increase in the ratio of tree leaves, the burning rate slightly increased. The highest burning rate was found in briquette F (0.947 kg/h) as follow by briquette E (0.940 kg/h), D (0.928 kg/h), C (0.924 kg/h), and B (0.918 kg/h), shown in Fig.5. According to an experiment by Nazari et al. (2019), the higher burning rate will result in briquette easier to start burning.

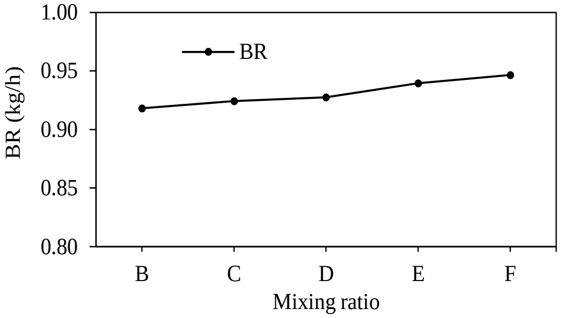

Fig.5. The burning rate of the various mixing ratio of tree leaves and sawdust with fish oil 10%

Heating values: The results of the heating value dry basis of samples B, C, D, E, and F were almost the same ranging from 21.21 MJ/kg - 22.15 MJ/kg as shown in Fig.6. The highest heating value was found in briquette D (22.15 MJ/kg) and the average heating value dry basis (21.76 MJ/kg) was higher than its raw material sawdust (21.49 MJ/kg) and tree leaves (19.89 MJ/kg). The heating value of these new composite briquettes obtained in the current study is higher than HV db of firewood (18-19 MJ/kg) and most agricultural residues (16-18 MJ/kg) reported by Sugathapala et al. (2013), sawdust and rice husk briquette (19.84-20.25 MJ/kg) obtained by Choeng et al. (2019). This heating value is sufficient enough to produce the heat required for household cooking and small-scale industrial applications.

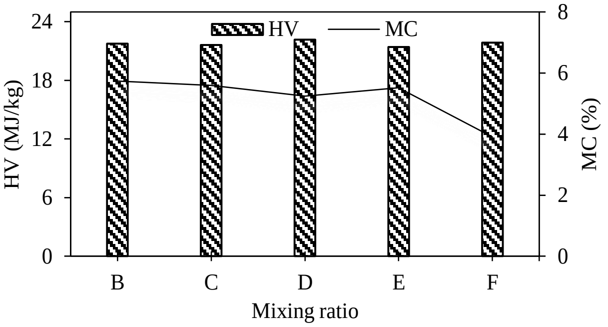

Fig.6. Heating value and moisture of different tree leaves and sawdust with fish oil 10% at the various mixing ratio.

Moisture content: Yang et al. (2005) reported that moisture content is a very important property that can greatly affect the burning characteristic of biomass. Aina et al. (2009) described that moisture content is one of the main parameters defining briquette quality as lower moisture content of briquettes infers higher calorific value wet basis. Regarding Fig.8, the moisture content of tree leaves sawdust briquette was between 3.91% and 5.93% wb. This is within the limit of 15% recommended by Wiliapon (2008).

3.5 Proximate analysis

Volatile matter (VM) characterizes the components of carbon, hydrogen, and oxygen present in the biomass that turn to vapor when heated, usually a mixture of short and long-chain hydrocarbons (Chaney, 2010). From proximate analysis showed in Fig.7, the percentage of volatile matter for tree leaves sawdust briquette among the five samples were almost the same (75.66% to 76.56%). Loo and Koppejan (2008) reported that biomass generally has a volatile content of around 70-86% of the weight of the dry biomass which makes biomass a more reactive fuel giving a much faster combustion rate during the devolatilization phase than other fuels such coal.

Ash which is the non-combustible component of biomass was determined to be 2.33% and 4.35%. According to Kim et al. (2001), ash has a significant influence on the heat transfer to the surface of the fuel, as well as the diffusion of oxygen to the fuel surface during char combustion. Loo and Koppejan (2008), reported that the higher the fuel's ash content is the lower its calorific value.

Thus, the values of volatile matter and the ash content of the briquettes observed in this study are good and acceptable.

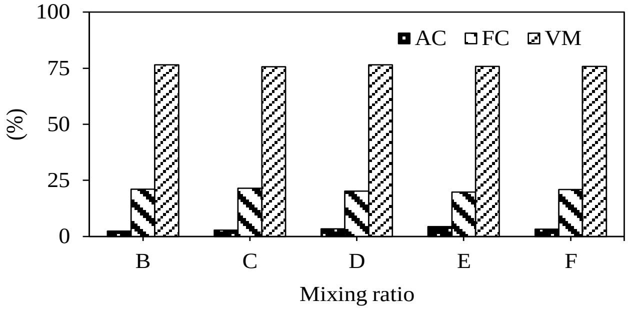

Fig.7. Proximate analysis of various mixing ratio of tree leaves and sawdust with fish oil 10%

The fixed carbon (FC) of a briquette is the percentage of carbon available for char combustion. The fixed carbon content was obtained between 19.82% and 21.50%. The fixed carbon of the current study was smaller than the total amount of carbon in briquette (ultimate carbon) since a significant amount was released as hydrocarbons in the volatiles.

4. CONCLUSIONS

The new finding of using fish oil at 10% as a binder has proved that the heating value dry basis of the briquette at a ratio of tree leaves and sawdust of 30:70 was 22.15 MJ/kg is higher than the heating value of sawdust 21.49 (MJ/kg) and tree leaves 19.89 (MJ/kg). The average heating value of the five ratios was 21.76 (MJ/kg), higher than the heating value of firewood, with moisture content between 3.91% and 5.93% wb, and the average density, energy density, and burning rate of briquette were 1.063 g/cm^3, 21.92 GJ/m^3, and 0.9314 kg/h respectively.

Sawdust can be a potential resource that leads to being used as a sustainable resource of biomass briquette due to its availability in Cambodia society.

ACKNOWLEDGMENTS

We would like to acknowledge ARES CUD Project and JICA LBE for financial support, and Dr. Chanmoly Or and Mr. Rithy Kan for supporting on measurement devices.

REFERENCES

Aina, O. M., Adetogun, A., & Iyiola, K. A. (2009). Heat energy from value-added sawdust briquettes of albizia zygia. Ethiopian Journal of Environmental Studies and Management, 2, 42-46.

Baran, E., Phen, C., Vuthy, L., Nasielski, J., Samadee, S., Bunthang, T., Tress, J., Khim, K., & Sokhom, T. (2014). Fish resources in Cambodia (2001-2011).

Basu, P. (2008). Biomass gasification, pyrolysis, and torrefaction: practical design and theory. Academic Press. San Diego.

Chaney, J. O. (2010). Combustion characteristics of biomass briquettes. Ph.D. Thesis. University of Nottingham, United Kingdom.

Chin, O. C., & Siddiqui, K. M. (2000). Characteristics of some biomass briquettes prepared under modest die pressures. Biomass and Bioenergy, 18, 223-228.

Choeng, P., Vongchanh, K., Or, C., Heang, L., & Chan, S. (2018). Proceedings of the 9th Conference on Thai Society of Mechanical Engineering, Phuket, Thailand.

Choeng, P., Heang, L., Vongchanh, K., & Chan, S. (2019). Proceedings of the 10th Conference on Mechanical and Manufacturing Engineering, 126-128, Phnom Penh, Cambodia.

Davies, R. M., & Abolude, D. S. (2013). Davies, R. M., & Abolude, D. S. (2013). Ignition and burning rate of water hyacinth briquettes. Journal of Scientific Research and Reports, 2, 111-120.

Deepak, K. B., & Jnanesh, N. A. (2016). Proceedings of the National Conference on Advances in Mechanical Engineering Science, 69-73, Sullia, India.

Döring, S. (2013). Power from Pellets. Springer: Berlin, Germany.

Griboff, J., Carrizo, J. C., Bonansea, R. I., Valdés, M. E., Wunderlin, D. A., & Amé, M. V. (2020). Multiantibiotic residues in commercial fish from Argentina. The presence of mixtures of antibiotics in edible fish, a challenge to health risk assessment. Food Chemistry, 332, 127380.

Inthavideth, X., Vongchanh, K., & Trichanh, P. (2017). The proceedings of the 10th Conference on Energy Engineering, Yangon, Myanmar.

Islam, M. H., Hossain, M. M., & Momin, M. A. (2014). Development of briquette from coir dust and rice husk blend: An alternative energy source. International Journal of Renewable Energy Development, 3, 119.

Joya, R. (2014). Biomass energy consumption patterns in Cambodia: challenges and opportunities.

Kim, H. J., Lu, G. Q., Naruse, I., Yuan, J., & Ohtake, K. (2001). Modeling on combustion characteristics of bio coal briquettes. J. Energy Resour. Technol., 123, 27-31.

Mitchual, S. J., Frimpong-Mensah, K., & Darkwa, N. A. (2014). Relationship between physicomechanical properties, compacting pressure, and mixing proportion of briquettes produced from maize cobs and sawdust. Journal of Sustainable Bioenergy Systems, 2014, 50-60.

Nazari, M. M., San, C. P., & Atan, N. A. (2019). Combustion Performance of Biomass Composite Briquette from Rice Husk and Banana Residue. International Journal on Advanced Science, Engineering and Information Technology, 9, 445-460.

Loo, S., & Koppejan, J. (2008). The handbook of biomass combustion and co-firing. Routledge: London.

Obi, O. F. (2015). Evaluation of the effect of palm oil mill sludge on the properties of sawdust briquette. Renewable and Sustainable Energy Reviews, 52, 1749-1758.

Puwastien, P., Judprasong, K., Kettwan, E., Vasanachitt, K., Nakngamanong, Y., & Bhattacharjee, L. (1999). Proximate composition of raw and cooked Thai freshwater and marine fish. Journal of Food Composition and Analysis, 12, 9-16.

Rajaseenivasan, T., Srinivasan, V., Qadir, G. S. M., & Srithar, K. (2016). An investigation on the performance of sawdust briquette blending with neem powder. Alexandria Engineering Journal, 55, 2833-2838.

Richards, S. R. (1990). Physical testing of fuel briquettes. Fuel Processing Technology, 25, 89-100.

Sugathapala, A. G. T., & Chandak, S. P. (2013). Technologies for converting waste agricultural biomass to energy. United Nations Environmental Programme, Osaka, Japan

Suprianto, F. D., & EVANDER, J. (2017). Proceedings of the 5th Asia Conference on Mechanical and Materials Engineering, 1-5, Tokyo, Japan.

Tabasso, S., Grillo, G., Mariatti, F., & Cravotto, G. (2020). Biomass Burning in Sub-Saharan Africa. Springer: Dordrecht, Netherlands.

Tun, M. M., Juchelkova, D., Win, M. M., Thu, A. M., & Puchor, T. (2019). Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries. Resources, 8, 81.

Wilaipon, P. (2008). Density equation of bio-coal briquettes and quantity of maize cob in Phitsanulok, Thailand. American journal of applied sciences, 5, 1808-1811.

Yang, Y. B., Ryu, C., Khor, A., Yates, N. E., Sharifi, V. N., & Swithenbank, J. (2005). Effect of fuel properties on biomass combustion. Part II. Modeling approach identification of the controlling factors. Fuel, 84, 2116-2130.