JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

THERMAL PROPERTIES OF BIOMASS BRIQUETTES MADE FROM WASTE MATERIALS

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Abstract: The waste materials including dried tree-leaves (DT), sawdust (SD), sugar bagasse (SB), and wasted paper (WP) are disposed by burned or collected and sent to the landfills. Burning these materials without applying the use of heat is a waste. Reversely, one method to make use of these wastes is to convert them to biomass briquettes. The proposed waste products are not always available everywhere and every time, therefore, the aim of this study was to produce the biomass briquettes with hexagon shapes using different mixing ratios and combined with 2 types of binders made from fish oil (FO) and waste oil (WO). The briquetting process used a screw press machine. To ensure and confirm the usability and capacity of the biomass briquettes, this paper presented an investigation of the thermal properties for 20 composited biomass, impact and water-resistant index for 35 samples, and the burning rate and flame temperature for 10 samples. The experimental results showed all 35 samples passed the impact-resistant test but only 5 of 35 samples passed the water-resistant test. Besides that, the heating value was obtained at about 17-23 MJ/kg, the energy intensity was in the range of 17-26.3 GJ·m^{-3}, the fixed carbon was 8.1-21%, the volatile matter was 69.7-81.5%, ash content was 2.3-14.6%, and moisture content was 2.5-6.3%. The highest flame temperature had the average highest burning rate and flame temperature at about 15 g·min^{-1} and 665ºC, respectively. The briquettes made from binders (FO and WO) had very similar characteristics and they can be used to replace wood.

***IndexTerms* – Biomass briquettes, Thermal properties, Physical properties, Waste to energy, Fish oil, Waste oil.**

I. Introduction

Waste collection and management is one of the main problems in Cambodia (Pheakdey et al. 2022). As we could observe in the actual situation, there are a lot of dried tree leaves, sugar bagasse, and waste paper; they were commonly collected and transferred to the landfill, which required labor and budget. In case another method to dispose of the waste is to burn the wastes including sawdust, waste paper, dried tree leaves, etc.; while, these materials could be used as a heat source. However, these materials have a low bulk density which is not convenient to use as heating material in its original form. Therefore; many studies have been working on the biomass briquettes, especially, in developing countries, (Ifa et al. 2020), (Lestari et al. 2017), (Birwatkar et al. 2014), (Shyamalee, Amarasinghe, and Senanayaka 2015), (Hafiz Muhammad Safdar Khan 2021). Developing and producing briquettes from waste materials are important; recycle of waste into briquettes reduces pollution prevents local deforestation rate, save time, and money, (Rwanda 2022), (Adeleke et al. 2021). Briquettes are more convenient to use, cheaper to transport, and easier to package and store than the original organic waste material and they also burn more efficiently (Katimbo et al. 2014). The briquettes can be utilized in both rural and urban settings for both home (cooking, heating, barbecuing) and commercial (agroindustry, food processing) purposes (Kathuria and Grover 2012).

Biomass briquettes were produced from waste, corncob charcoal, and sago stem alloys, higher pressure result in the decreasing of moisture content. The thermal properties were investigated, the ash content is found from 3.459% to 8.766%. Volatile matter and fixed carbon were varied from 13.658% and 21.168% and 67.667% to 80.758% respectively. The lowest burning rate is 0.09 g·s^{-1} and the optimum burning temperature is 499.2ºC with the lowest ignition time of 1.58 minutes, (Lestari et al. 2017). The physical and thermal properties of the briquette were determined by varying rice straw and sugarcane leaves ratios of 100:0, 80:20, 50:50, 20:80 and 0:100 using molasses as the binding agent. The high heating value was in the range of 16.3-17.83MJ·kg^{-1}. The density was in the range of 0.53-0.58kg·m^{-3} (Birwatkar et al. 2014). The samples with cow dung as a binding agent failed with mould detaching and the minimum required binder percentage for the other two binders for successful forming was found to be 30%. The density of briquettes with 30% binder of wheat flour and paper pulp was found to be 373.7 kg·m^{-3} and 289.8 kg·m^{-3}respectively, (Shyamalee, Amarasinghe, and Senanayaka 2015).

Heang et al., 2020 studied eleven compositions ratios of various tree leaves and sawdust (0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10, and 100:0) combined with 10% of each binder (fish oil & waste oil). Results showed that the ratio of 30:70 of tree leaves and sawdust with added 10% of fish oil as a binder was a suitable composition ratio for energy storage, strength, resistance to water absorption, and low moisture content (which is allowable for long-term storage), and easy to burn, (Heang 2020). Cheng et al., 2020 investigated mixing ratios of bagasse and rice husk (100:0, 75:25, 50:50, 25:75, 0:100) with 10% of each binder (fish oil & waste oil). The results showed that briquettes 50:50 had a moderate value range on density, heating value, and energy density, while the value of briquettes was in the range of 0.92-1.25 g/cm3 the density, 17.98-20.38 MJ/kg the heating value, and 18.69-22.69 GJ/m3 the energy density. Briquette 50:50 had higher heating value, energy density, and lower burning rate; however, briquette 100:0 and 0:100 also had lower heating value, energy density, and higher burning rate over briquette 50:50, (Choeng 2020).

Four types of city wastes, including dried tree-leaves (DT), sawdust (SD), sugar bagasse (SB), and wasted paper (WP), were selected to produce briquettes because they are available inside Phnom Penh. Rice husk (RH) was chosen to be the mixing material because it has a high heating value and it is available outside Phnom Penh. Thus, the expected briquettes can be produced everywhere in Cambodia. In this study, Fish oil (FO) and waste oil (WO) were used as the binders for the briquetting process. The purpose of this paper was to provide the possibility to reuse of waste from different city waste materials and available materials in the rural area. To verify the usability of the briquettes, the thermal and physical properties were presented in this paper.

II. RESEARCH METHODOLOGY

2.1 Raw materials

Sugar bagasse (SB), dried tree leaves (DT), sawdust (SD), and waste paper (WP) were collected from the sugarcane shops, the Institute of Technology of Cambodia; the furniture workshop, photocopy shops in Phnom Penh, respectively. Rice husk (RH) was ordered from outside Phnom Penh, shown in Fig.1.

WO was purchased from Fast-food companies or from deep-fried shop. Fish oil (FO) was extracted from the fish fat which was purchased from the local market.

Figure 1. Collecting the raw materials

2.2 Material preparation and experimental procedure

There are 35 samples made from 5 raw materials including SB, DT, SD, WP, and RH; the mixing ratio of each sample were described in Table 1. The required particle size of raw material must be less than 8 mm before the mixing process. Therefore, DT, SB, SD, and WP were required to crush or filter for the suitable particle size. Rice husk could be started directly into the mixing process. For the mixing process, (Heang 2020), first, mixing the raw material with the required ratio in the mixing machine after that, 10% of the binder (FO or WO) was added and mixed for 5 mins or more until the binder and raw materials were homogenous. Then, the mixed materials were transferred to the hopper for feeding to screw press briquetting machines; next, the briquetting process was started. Finally, products as briquettes were obtained, see Fig.2.

Figure 2. Briquetting process

Table 1. The mixing ratio of the briquettes

Binder	Materials	Mixing ratio	Binder	Materials	Mixing ratio	Binder	Materials	Mixing ratio
FO (10%)	DT:SD (Heang 2020)	10:90	WO (10%)	SB:RH (Choeng 2020)	0:100	WO	SD:WP	80:20
		20:80			25:75			75:25
		30:70			50:50			70:30
		40:60			75:25			65:35
		50:50			100:0			60:40
	SB:RH (Choeng 2020)	0:100		DT:SD (Heang 2020)	10:90	NOTE:		
		25:75			20:80	WO: Waste oil		
		50:50			30:70	FO: Fish oil		
		75:25			40:60	DT: Dried tree leaves		
		100:0			50:50	SD: Saw dust		
	DT:SB	10:90		DT:SB	10:90	SB: Sugar bagasse		
		20:80			20:80	RH: Rice husk		
		30:70			30:70	WP: Waste paper		
		40:60			40:60			
		50:50			50:50			

2.3 Water Resistance Index (WRI)

The water resistance test was adopted from (Richards 1990). The process of the water resistance test was described in Fig.3. Firstly, the briquettes (samples) were prepared, and measured the mass of each sample. The water at room temperature 30℃ was filled in a tank. After that, the prepared samples were immersed in the prepared water. If the briquette can survive in 30 mins; then the samples were removed from the tank and wiped to remove the moisture from the surface briquettes; finally, measured the mass of the immersed samples. The WRI was calculated using Eq.1.

$$\text{WRI} = 100 - \%\ \text{Water adsorbed} \qquad (1)$$

Prepare samples | Measure water temperature | Measure mass before immersion | Soaking samples with water | After immersion | Measure mass after immersion

Figure 3. WRI test process

2.4 Impact Resistance Index (IRI)

A practical performance targeting 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 as shown in Fig.4. This test contains averaging the results of 5 single drop tests. Each briquette was repeatedly dropped until it fractures, piece of mass that was greater than 5% of the initial mass was counted. The number of drops and the number of pieces of briquette was recorded. An IRI value of 50% has been adopted as being the lowest acceptable impact resistance for fuel briquettes being developed for industrial, (Richards 1990). The IRI can be calculated using Eq.2.

$$IRI = \frac{\text{Average number of drops}}{\text{Average number of pieces}} \times 100\% \qquad (2)$$

Measure mass of samples before impact test | Impact test | Measure mass of samples after impact test

Figure 4. IRI test process

III. Result and discussion

The purpose of testing the water resistance index (WRI) and impact resistance index (IRI) referred to the capacity of the briquettes against absorption of water and disintegrations during handling, storage, and transportation. The IRI of 50% was benchmarked for briquettes of industrial application and the good WRI is required higher than 95%. The higher the WRI is the better the resistance against water absorption and disintegrations, (Adeleke et al. 2021) and (Richards 1990). In this study, IRI and WRI were experimentally investigated for 35 samples and described in Fig.5.

The IRI results clearly showed that all samples had a value higher than 50%, which means higher than the benchmarked value, the briquettes could handle transportation and storage. However, only some samples including DT:SD:FO (10:90, 20:80, and 30:70), SB:RH:FO (100:0), and DT:SB:FO (10:90, 20:80, and 30:70) passed WRI test. The other components of the briquette's materials had lower WRI values than 95%; it did not mean these compositions could not be stored, but those briquettes could store for a longer or shorter period of time accordingly.

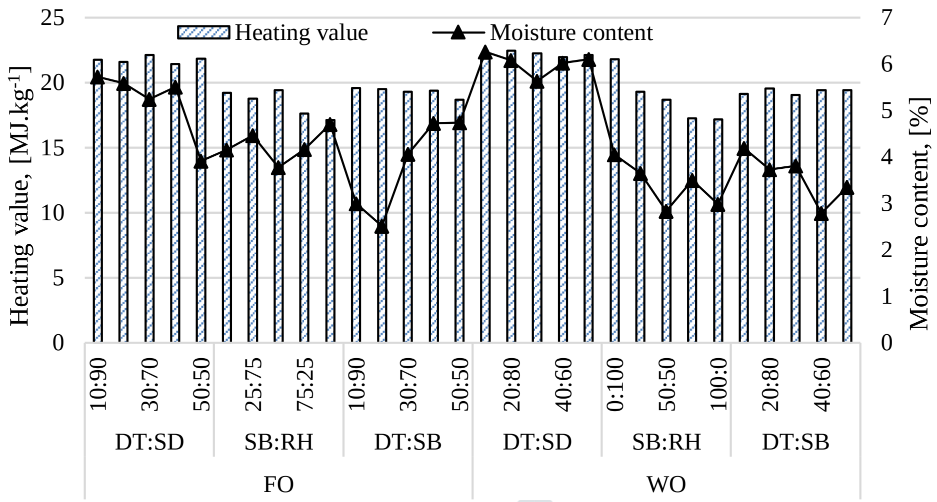

Figure 5. Impact resistance index and water resistance index

The moisture content (*MC*) of the briquettes was experimentally obtained about 2-7%wb. The moisture content of 30 samples with different compositions from four types of waste (ST, SD, SB, and RH) was described in figure 6. The average moisture content of the briquettes was 4.4% (min=2.5%, max=6.3%, SD=1.0%). The average highest *MC* (ave. *MC*=6.0%) was found in samples that were made from the composition of DT:SD:WO. Generally, the moisture content of the briquette is expected to be low because the lower its moisture content had the higher its burning power.

The heating values (HV) were experimentally investigated; the average heating value was about 20 MJ·kg^{-1} (min=17 MJ·kg^{-1}, max=22.5 MJ·kg^{-1}, SD=1.7 MJ·kg^{-1}), as shown in Fig.6. The highest HV was found in the briquettes made from DT:SD: WO and FO, 22.1 MJ·kg^{-1} and 21.8 MJ·kg^{-1} respectively. The lowest heating value was found in compositions of SB:RH: WO and FO. Although, the lowest HV of these briquettes, but they were mostly higher than the heating value of firewood, sawdust, dried tree leave, rice husk, and sugar bagasse (17.5, 18.4, 17.2, 14.7, and 16.1 MJ·kg^{-1}), which were carried out within this study. Regarding the heating values of these briquettes, they could be used to replace the firewood.

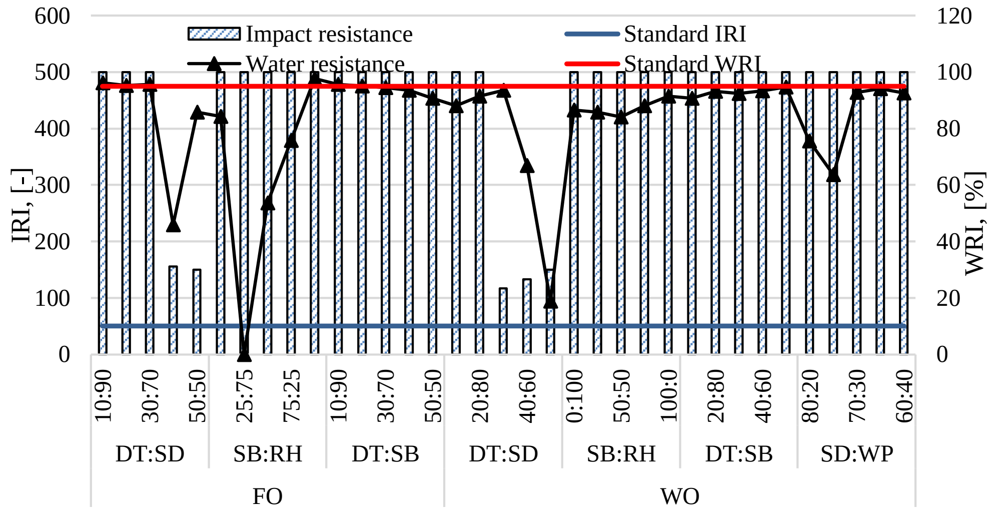

Figure 6. Heating value and moisture content

The density of different mixing ratio for 35 samples were measured. The minimum and maximum density values were found from the briquettes made from DT50:SD50:FO10 (895 kg·m^{-3}) and SB100:WO10 (1,220 kg·m^{-3}), respectively. Comparing the density by group, the briquettes made from DT:SD: FO/WO were high density without any effect of binders. The higher briquette density made from SB:RH:FO/WO was obtained from the increase of the mixing ratio of SB; however, only the mixing ratio RH100:FO/WO was found lower than expected that would cause by the feeding process. Next, briquette density made from DT:SB:FO/WO and SD:WP:WO were having similar values. Finally, the density value of 28 samples were higher than 1000 kg·m^{-3}. Only 7 samples were under expectation, as depicted in Fig.7. The average energy intensity from 30 samples were about 21.6 GJ·m^{-3}, which was higher than the energy intensity of raw material.

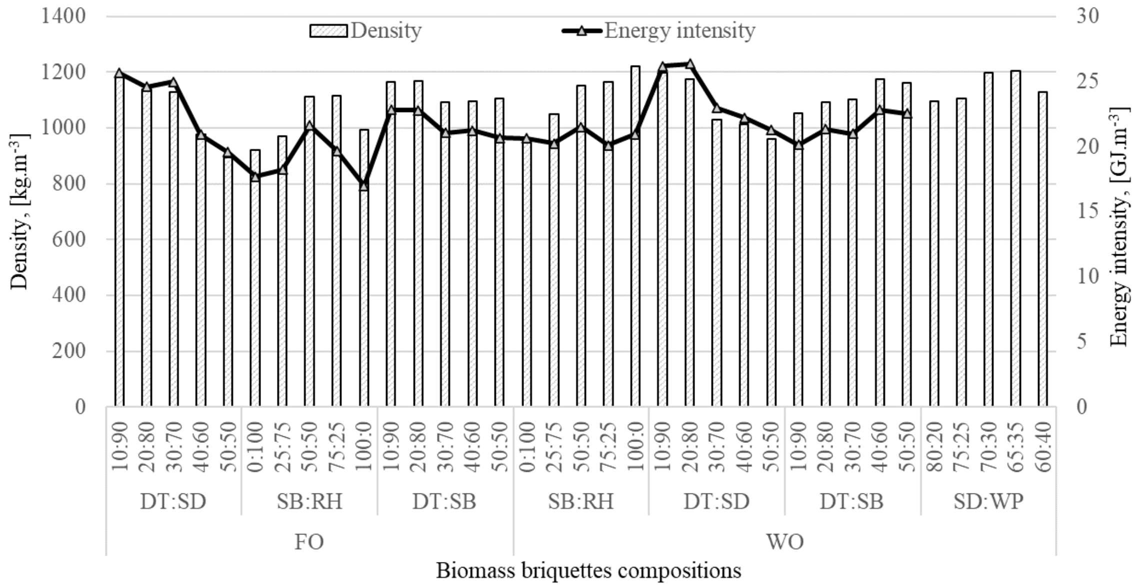

Figure 7. Density and energy intensity

The proximate analysis was done for 20 samples obtaining from DT, SD, SB, RH, and two binders (FO and WO); the results were shown in Fig.8. High volatile matter content is an indication of the readiness of fuel samples to ignite. A high percentage fixed carbon is an indication of a high heating value of the briquette.

The average volatile matter (VM) was 75.7% (min=69.8%, max=81.5%, SD =2.9%); thus, all the 20 samples were within the recommended range between 60-80% (Japanese standard) (Lestari et al. 2017), which indicated the readiness of the briquettes for ignition. The two highest volatile matter (80.3% and 81.5%) were found in the composition material from SB:RH:FO, 75:25:10 and 100:00:10, respectively.

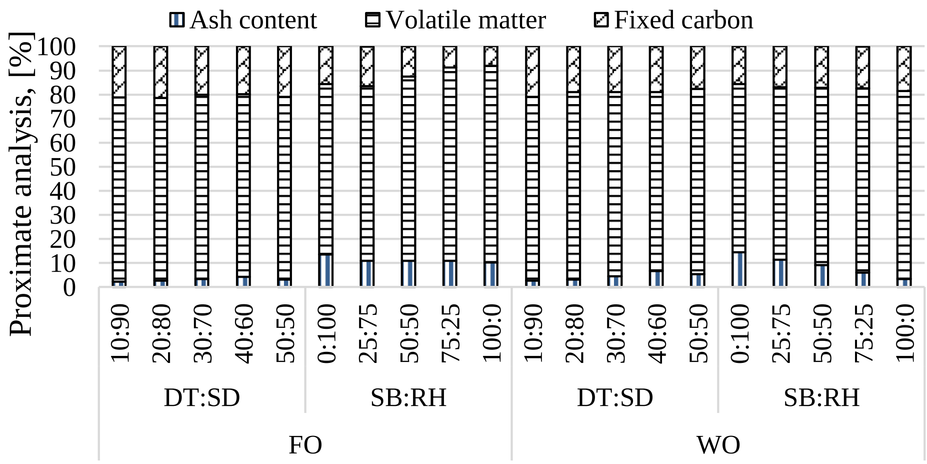

Figure 8. Proximate analysis results

The fixed carbon (FC) content from 20 samples had an average value of 17.3% (min=8.1%, max= 21.5%, SD=3.8%) which was within the recommended range (15-30%). The high fixed carbon content was found in the composition of biomass from DT:SD:FO/WO with an average value of 20%. For the FC less than 15% was found in SB:RH:FO (50:50, 75:25, and 100:00). Although the three briquettes having low FC, the heating values were between 17.1-19.4 $MJ\cdot kg^{-1}$ which was higher than the heating value of SB and RH (16.1 $MJ\cdot kg^{-1}$ and 14.7 $MJ\cdot kg^{-1}$), respectively.

The mean ash content was 6.9% (min=2.3%, max=14.6%, SD=3.4%) which means the average ash content of 20 samples was slightly higher than the recommended range of ash content (3-6%, Japanese standard, [3]); however, the highest value of ash content was found in the composition of SB:RH:FO having an average ash content of 11.3%.

Moreover, mass reduction of the briquettes during the combustion process and the burning rate were experimentally studied with 11 samples made from ST:SB:FO and WO and firewood, using approximately 2 kg consisting of 3 pcs of briquettes (about 750 g per pc) for the combustion (burning) process in a conventional cooking stove; the mass reduction and burning rate profiles were described in Fig.9 and 10, respectively.

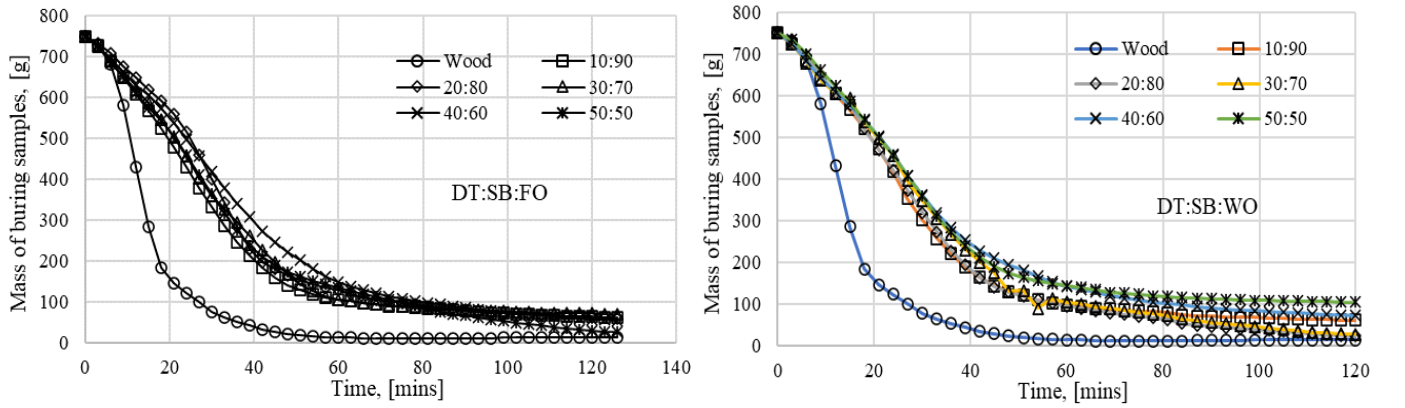

Figure 9. Mass reduction profile of DT:SB:FO and WO

Each experiment spent about 120 mins to complete the burning process; the burning rate investigation clearly showed that 10 samples had very similar average burning rates, about 11 $g \cdot min^{-1}$; while the average burning rate of firewood, about 14.5 $g \cdot min^{-1}$, was higher than biomass briquettes. Because the higher burning rate of firewood caused the mass reduction of firewood was faster than briquettes; the burning period of firewood and briquettes with flame temperature of 200°C could last about 35 mins and 60 mins, respectively, as illustrated in Fig.11.

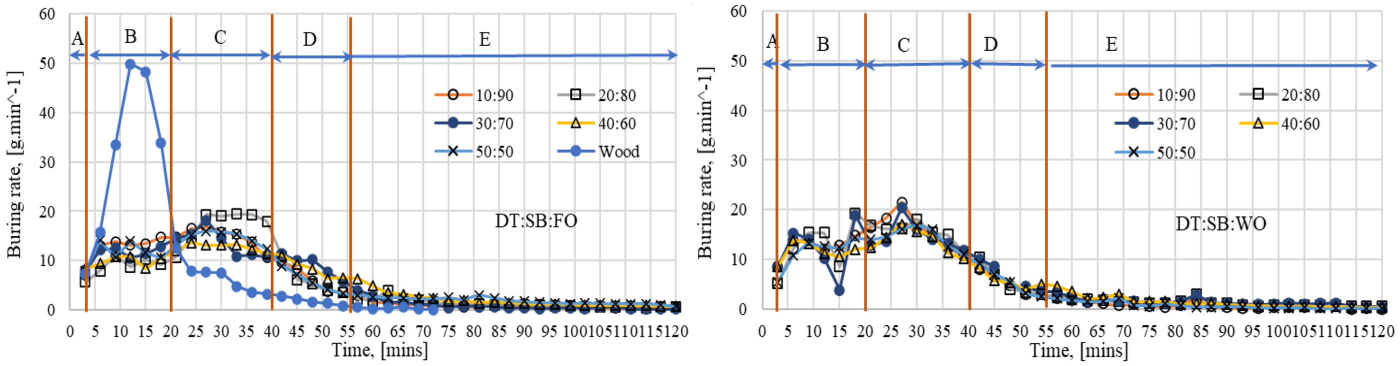

Figure 10. Burning rate profile of DT:SB:FO and WO

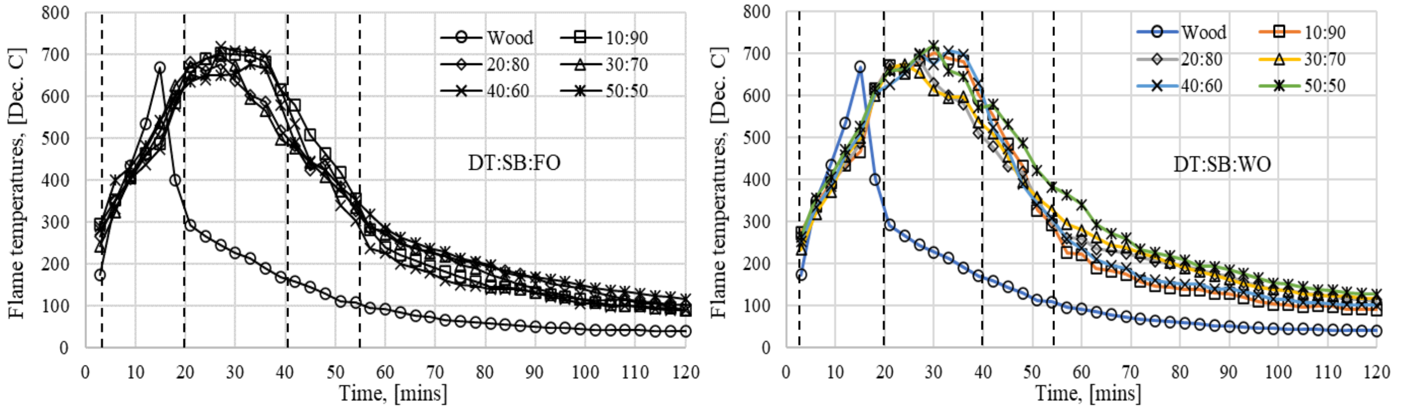

Figure 11. Flame temperature of DT:SB:FO and WO

The flame temperature (T_f) of the firewood was lower than briquettes; the average flame temperature of firewood and briquettes within the first 40 mins of burning was about 308°C and 548°C, respectively, see Table 2. The burning rate of briquettes was divided into five zones (A: starting, B: increasing, C: highest, D: decreasing, E: ending). The period A was the ignition period, it took about 3-5 mins to start the fire, during period A, the average flame temperature was rapidly increased. The Period B (3-20 mins), the flame temperature started increasing then it reached the highest T_f in period C having the average highest burning rate and the average highest flame temperature (about 15 $g \cdot min^{-1}$ and 665°C), respectively. After that, the burning rate started reducing after about 40 mins (period D) obtained the average flame temperature 422°C. In the last period E started about after 55 mins (T_f =300°C), and the average burning rate and the flame temperature started reducing to very low temperature, 1.4 $g \cdot min^{-1}$ and 164°C, respectively.

The burning rate of firewood after the ignition period A; then period B and C were together. The burning rate was going up very rapidly to the highest burning rate and flame temperature (50 $g \cdot min^{-1}$ and 668°C) after that the burning rate and the flame temperature went down rapidly from the highest to 300°C in 20 mins. Finally, the burning rate of the firewood was very slow and provide a low flame temperature which was between 300-100°C for 25 mins (lower T_f of the briquettes).

Table 2. Burning rate and average flame temperature of briquettes made from ST and SB

Mixing ratio	Ave. Burning rate DT:SB, [g.min^{-1}]		Ave. Flame Temp (3-40 mins), [ºC]		Ave. Flame Temp (3-120 mins), [ºC]	
Wood	13.57		308.55		146.3	
	FO	WO	FO	WO	FO	WO
10:90	11.67	11.85	564.88	553.86	311.81	295.92
20:80	11.23	11.86	554.62	553.86	319.46	306.52
30:70	11.53	12.24	533.88	523.26	305.34	310.39
40:60	10.50	10.80	555.07	554.07	297.96	302.55
50:50	11.07	11.00	552.57	559.38	325.31	341.05

IV. Conclusion

The experimental work was carried out for 35 different mixing ratios for testing the impact resistant index and the water resistant index; but only 20-30 different mixing ratios were investigated for the thermal properties due to limitations and availability of the measuring equipment and devices. The results showed that all these 35 mixing ratios can be formed. The proximate analysis was done for 20 samples consisting of biomass materials from DT, SD, SB, RH, and two binders (FO and WO). The properties of the briquettes made from FO and WO had very similar characteristics.

The results of this study, all these briquettes had high heating values (ave. 20 MJ·kg^{-1}) and good WRI and IRI. The average ash content, fixed carbon content, and volatile matter were about 6.9%, 17.3%, and 75.7%, respectively. The average energy intensity (EI) was about 21.6 GJ·m^{-3}; it is surely higher EI than raw material. The average burning rate and temperature of the wood and briquettes during 3-21 mins were 28.7 g·min^{-1} & 12.4 g·min^{-1} and 407.6ºC & 414.3ºC, respectively. Within the first 40 mins of the combustion process using the briquettes (FO &WO) and wood had an average flame temperature of about 548ºC and 308ºC, respectively; it means the briquettes provides higher temperature with a longer combustion duration than wood. The experimental results showed that the briquettes can be used as a replacement of firewood because the flame temperatures, burning rate, MV, FC values were similar and higher than firewood.

The proposed mixing ratios from dried tree leaves, sugar bagasse, rice husk, and waste paper could produce the briquettes using the screw press machine. The briquette producer is possible to select the raw materials according to the availability nearby the production area. Therefore, if the waste products are chosen to be reused; it is possible to reduce the waste in landfill. Finally, gas emissions are suggested to be invested.

V. Acknowledgment

ARES-CCD and JICA LBE are acknowledged for their financial support. The authors would like to thank the Biomass laboratory at ITC for allowing us to use some of the measuring equipment. We also thank Mr. Sony Kor for their effort and time to conduct part of the experiment in this study. Finally, Mr. Porchieng Choeng is highly acknowledged for conducting the experiment in this study and he has also improved the briquetting machine.

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