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Preparation of Biomass Briquettes using Durian Peel Char and Spent Mushroom Compost Char

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Abstract – *Durian peel (DP) and spent mushroom compost (SMC) are considered as agricultural wastes. These two materials have potential for the briquetting process according to their quantities. In this study, cold densification method and extrusion process are adopted for solid bio-fuel briquettes. DP and SMC were pyrolysed, milled and combined together by adding 10% of cassava starch as a binder. The study has varied the mass ratio of DP and SMC chars at 10:0, 8:2, 6:4, 4:6, 2:8 and 0:10 respectively. Physical properties of the briquettes were investigated for heating value, ash and moisture content. The results show the highest heating value of 5,880 cal/g and 5,303 cal/g for the briquette made with DP and the mixture of DP and SMC at a mass ratio of 8:2 (Mix 4), respectively. The lowest ash content of 7.9% and 12.4% for the briquette made with DP and Mix 4, respectively. A heating value higher than 5,000 cal/g is acceptable in the market according to the Thailand community standard. DP and Mix 4 briquette had a good propertied as fuel and suitable as an environmentally friendly alternative energy source. Moreover, a payback period of DP and Mix 4 briquette less than three years can be achieved.*

Keywords – *agricultural waste, briquettes, durian peel char, fuel properties, spent mushroom compost char.*

1. INTRODUCTION

Biomass is the organic material from plants that live or once lived within the earth's biosphere. The most important biomass energy sources are agricultural residues such animal waste, fruit waste, waste from food processing [1]. Biomass fuel is becoming more attractiveness as a suitable substitute for fossil fuels due to the increasing demand for clean energy [2]–[3]. Therefore, biomass is considered to be the renewable energy source with the highest potential to contribute to the energy needs of modern society for developed and developing nations, while providing less harm to the environment [4].

The process of producing briquette can be utilized from agricultural and industrial waste. These materials usually contain low density and high volume, causing in convenient to transport and store. Making a briquette has more advantages as it is convenient to store, transport and utilize. Furthermore, the compressing of this material is the method to improve their calorific value and density in order to compensate the firewood and wood charcoal [5].

As the mushroom industry continues to grow and develop, spent mushroom compost (SMC), production is therefore also increasing. In 2016, SMC was produced about 120,000 ton/year in Thailand [6]. Disposal is often problematic due to the large quantities of products, particularly as it is disposed of in landfill sites or is spread as a fertilizer on agricultural land; both are unsustainable and environmentally degrading, and consequently disposal is the most significant barrier to future developments in this industry. Although a number of studies have investigated a variety of possible uses for SMC, mainly agricultural and industrial applications, few have considered its use as a potential energy feedstock. For example, SMC can be combusted in a bubbling fluidised-bed, creating superheated steam to generate power with high efficiency and recover the heat [7]. However the bulk density SMC is sixfold less that of hard coal. Low bulk density could be possible cause problems during transport of fuel and may require large areas to store the material. Ash in SMC constitutes approximately 31% (dry basis) which is more than the ash content in the hard coal [8].

Mixed biomass contains two or more kinds of biomass; the advantage of using more kinds of biomass includes the possibility of improvement of final bio-fuel parameters by a combination of different chemical and mechanical properties of used biomass kinds. The suitability of digestate for bio-briquette production was already proved in a study conducted by Brunerová *et al.* [9].

Durian peel (DP) is one of the agricultural residues that have rarely been considered and promoted. In Thailand, durian is grown in the eastern and southern area. The total durian product of the country is about 734,284 tons a year in 2018 [10]. The domestic consumption is approximately 350,000 tons per year therefore, two-thirds of the whole fruit is left to waste as peel. The calculation of durians peel gives about 230,000 tons each year. The massive amount of the peel is disposed as waste which could lead to environmental problems. The proximate analysis for durian peel has shown carbon (C), oxygen (O) and hydrogen (H) components of 60.31%, 28.06% and 8.47% respectively

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[11]. Compare those three main chemical elements, the durian peel has high carbon. Moreover it has high calorific value and does not produce gas SO [12]. This figure of durians peel has shown its potential in terms of energy and quantity for the briquette production process.

Therefore, this research investigated the briquette production by various mass ratios of SMC and DP chars. A screw press process is selected for briquetting due to its simplicity, convenience and low cost. Physical properties including the heating value and moisture contents are examined in the laboratory testing. An economic feasibility is presented through a simple payback period.

2. METHODOLOGY

2.1 Materials

The raw materials as SMC and DP are collected for free from the available source located in Nakhon Si Thammarat province of Thailand. SMC (initial moisture content of 83% w.b.) and DP (initial moisture content of 58% w.b.) are dried in the sun down to moisture content of 15%. The drying time of SMC and DP were 5 and 10 days, respectively.

2.2 Pyrolyzer

A 200-liter-vertical-oil-drum kiln (Figure 1) was used for pyrolysis of SMC and DP. It consists of a door located towards the bottom to allow the controlled inflow of the primary air that allows the fire to ignite and grow. The pyrolyzer contains three chimneys with cooling attached at the bottom of the pyrolyzer. A fourth chimney is located at the top of the pyrolyzer and it provides an outlet for smoke.

After installation 15-20 kg of SMC or DP was loaded in the pyrolyzer and was pre-heated to dehydrate the raw material (Figure 1a) until the smoke turned white (Figure 1b). During pyrolyzer operation, the bottom door is propped open until the fire is self-sustaining (temperature of 250°C), at which point it is closed and all possible cracks are blocked to restrict the levels of oxygen inside to create environment favorable for the pyrolysis. It is also necessary to cover the kiln completely by placing a lid at the top of chimney (Figure 1c). After the carbonization process, the pyrolyzer was allowed to cool to a room temperature. Then, a charcoal was collected and calculated the percent yield.

(a) Dehydration (b) Ignition (c) Carbonization

Fig. 1. The 200 L pyrolyzer.

2.3 Charcoal Briquettes Production

The charcoal from pyrolyzer was then down-sized using a blender and filtered by using a 60 mesh filter. A total of six different samples were prepared in varying ratios of DP to SMC (Table 1). Making briquettes process consisted of charcoal amounting to 60%, cassava starch 10% and water 30% of the total briquette weight. A cold densification method is employed in which a binding material is necessary to unite the materials. Cassava starch is used to bind the char mixture. The natural binder liked starch obtained from cassava flour has proved that it is strengthen briquette and combine it quite efficient [13]. The screw press machine is utilized to form the briquette. The combined chars are fed into the extruder as shown in Figure 2. The cylindrical briquetting has inner diameter 5 cm and height 9 cm. This product is dried and used as a fuel. In order to indicate the feasibility of utilizing the briquette, its physical properties are analyzed under standard testing methods.

2.4 Meshing

2.4.1 Physical property

The heating value of the briquette was determined using the IKA C5000 Basic bomb calorimeter in accordance with ASTM D5865-13 (2013). One gram of sample was pelletized, placed in a sample holder and then transferred to a steel capsule from the bomb calorimeter.

The test was performed at the Office of Scientific Instrument and Testing, Prince of Songkla University, Thailand.

2.4.2 Chemical properties

Chemical properties of this experiment includes moisture content, volatile matter and ash content were determined by using the chemical analysis of wood charcoal in accordance with ASTM D-1762-84 (1996). The chemical properties of briquette were conducted in the Laboratory at the Office of Scientific Instrument and Testing, Prince of Songkla University, Thailand.

Table 1. Material composition of DP and SMC briquettes.

No.	Sample name	Material composition (%)	
		Durian peel char	Spent mushroom compost char
1	DP	100	0
2	SMC	0	100
3	Mix 1	20	80
4	Mix 2	40	60
5	Mix 3	60	40
6	Mix 4	80	20

Fig. 2. The charcoal briquettes from a screw press briquette with motor.

The moisture content was determined as loss in weight in a drying oven at 105°C. The same specimen was used for volatile matter and ash content determination.

The volatile matter was determined as loss of weight at 950°C by preheating the specimen in the muffle furnace for two minutes at 300°C then heating for three minutes at 500°C, finally for six minutes at 950°C in covered crucible of specimen by lid. Volatile matter was calculated as a proportion of oven-dry weight of charcoal specimen.

The ash content was determined as the residue after burning of specimen to constant weight at 750°C for six hours in uncovered crucible of specimen. Ash content was computed as a proportion the residue to the oven-dry weight of charcoal.

2.5 Economic Analysis

The cost analysis was carried out as complete briquettes processing of SMC and DP chars by screw press technologies, in order to compare the three types of combinations briquettes in respect of their economics.

Economic indicators were used for economic analysis of briquettes prepared from SMC and DP chars biomass under this study.

1. Net present worth (NPW)
2. Internal rate of return (IRR)
3. Payback period (PBP)

2.5.1 Net present worth (NPW)

The present values of the future returns calculated through the use of discounting. Discounting was essentially a technique by which future benefits and cost streams can be reduced to their present worth. The process of finding the present worth of a future value is called discounting. The discounting rate is the interest rate assumed for discounting. The most discounted cash flow measure of project worth is the net present worth (NPW). NPW may be computed by subtracting the total discounted present worth of the cost stream from that of the benefit stream.

$$NPW = \sum_{i=1}^{n} \frac{B_t - C_t}{(1+i)^t} \quad (1)$$

Where:

C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = Discount rate

2.5.2 Internal rate of return (IRR)

Another way of using the incremental net benefit stream or incremental cash flow for measuring the worth of a project is to find the discount rate that makes the net present worth of the incremental net benefit stream or incremental cash flow equal to zero. This discount rate is called the internal rate of return. It is the maximum interest that a project could pay for the resources used if the project is to recover its investment and operating costs and still break even. It is the rate of return on capital outstanding per period while it is invested in the project. IRR is a beneficial measurement of project worth.

$$\sum_{i=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad (2)$$

2.5.3 Payback Period (PBP)

The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.

3. RESULTS AND DISCUSSION

3.1. *The Properties of Raw Materials*

The values in Table 2 show the proximate analysis of SMC and DP in this study, along with comparative values found in the literature. It can be seen that the percent yield of charcoal from DP is slightly higher than from SMC. DP and SMC are a high lignocellulosic biomass composed mainly of 40.92, 42.4% cellulose and 25.45, 22.7% lignin, respectively [14]. The cellulose biomass contents are generally the main source of volatiles, whereas lignin corresponds to yields and energy [15]. These results confirm that DP had higher yield and heating value than SMC. But DP had lower volatile matter than SMC. SMC had higher ash content than DP. But SMC had lower fixed carbon compared with DP because the major component of SMC is rubber wood which has high ash content, high volatile matter and low fixed carbon [16].

However, all proximate analysis values obtained for this study are within the range reported by the literature listed in Table 2. The heating value of SMC does not meet the charcoal briquette quality of Thai Industrial Standards Institute standard which required not less than 5,000 cal/g [17], due to the low heating value for charcoal briquette production. SMC needs to be improved for product of charcoal briquette by mixing with DP.

Table 2. Percent yield of charcoal and proximate composition of charcoals from SMC and DP.

Composition of charcoals	Materials		Literature Data	
	DP	SMC	Williams *et al.* [18]	Rochim *et al.* [19]
Yield of charcoal	34.0±4.4	30.9±2.4	NA	NA
Moisture content (%w.b.)	6.2±0.5	6.7±0.3	NA	NA
Ash content (%w.b.)	7.9±0.51	26.7±2.0	27.0-33.4*	10.15
Volatile matter (%w.b.)	46.7±4.9	52.2±4.9	57.0-59.1*	41.90
Fixed carbon (%w.b.)	39.1±4.8	14.1±1.7	9.6-14.9*	47.95
Heating value (cal/g)	6,378±31	3,211±123	2,892.4-3,272.2*	6,274.29

* Dry basis
NA means not available.

3.2 *Briquette Characterization*

3.2.1 Moisture content

Moisture content is an important parameter for evaluating changes that may occur in the physical conditions of briquettes during storage and transport. The moisture content values obtained in this study ranged from 6.2% for DP to 6.7% for SMC briquette (Figure 3). According to Chin and Siddiqui [20], the tolerance levels of moisture content for briquette depend on the nature of the feedstock.

The moisture content of all charcoal briquettes must be reached meet the requirement of Thai community production standard 238/2547 [21], therefore they are drying by sunlight. According to the standard, the moisture content of all charcoal briquettes is less than 8%, which is low and can be a good indicator of solid fuel. If the charcoal briquette contains high moisture content, then the heating value decreases during combustion, the moisture in the biomass will absorb heat from the burning fuel to form vapor due to heat of vaporization, thereby appreciably reducing the heating value of a used fuel. This can result in incomplete combustion of the volatile matter and the deposition of unburnt carbon (smoke) around the stoves, vessels and pans, making it difficult to clean them [22].

3.2.2 Volatile matter

Volatile matter represents the components of carbon, hydrogen and oxygen present in the biomass, which when heated is converted to vapor, usually a mixture of long-and short-chain hydrocarbons. Generally, the higher percentage of volatile matter is an indication that the ignition rate will be high [23]. As shown in Figure 4, the DP briquette recorded the volatile matter of 56.7% which was closely followed by the Mix 4 briquette with a value of 56.1%. The amount of volatile matter decreases when the quantity of SMC increases because SMC has sand and soil which is not converted to vapor.

3.2.3 Ash content

Ash is the non-combustible component of a biomass. It is formed from both the mineral matter bound in the carbon structure of the biomass during its combustion and is presented in the form of particles from dirt and clay introduced during processing. Ash is known to cause problems in combustion systems, notably because of formation of slag and deposition over the surface of the metals and its tendency to increase the rate of corrosion of the metal in the system.

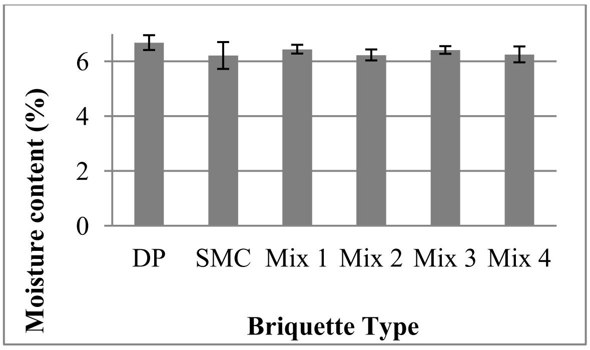

Fig. 3. Moisture content of briquettes.

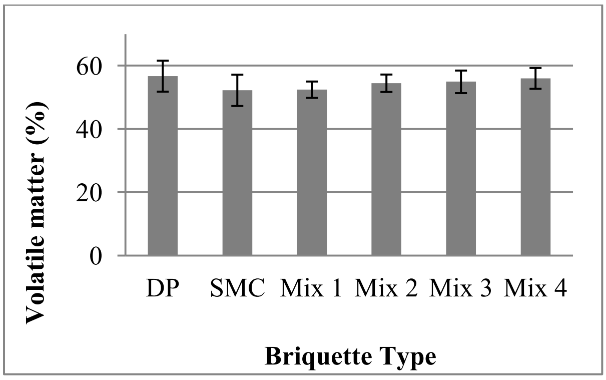

Fig. 4. Volatile matter of briquettes.

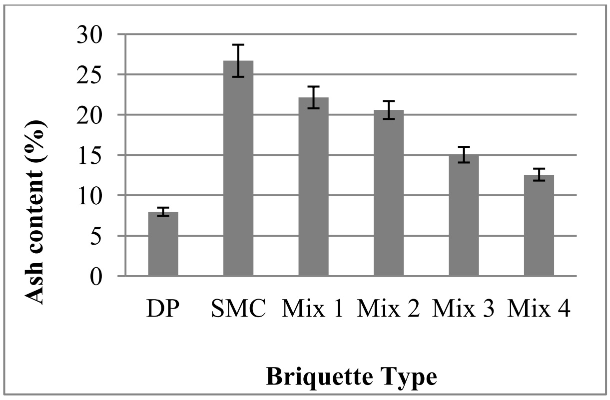

Fig. 5. Ash content of briquettes.

The high ash content as observed in this study (Figure 5) is a reflection of heating value (Figure 7) which is an indication that the briquette contains high mineral (non-combustible) matters. The ash content was only higher in treatments where SMC was presented in the briquettes composition. In this condition, the ash contents ranged from 7.97% to 26.68% when briquettes with SMC were used in proportions ranging from 0% (DP) to 100% (SMC). According to Sultana *et al.* [24], ash contents between 0.5% and 12.5% are commonly observed after the combustion of biomass. Values above these may indicate that the material is contaminated and constituted a potential pollutant. DP and Mix 4 briquette do not exceed the ash content of 12.5% which has a good propertied as fuel.

3.2.4 Fixed Carbon

The fixed carbon (%wt) is normally determined by subtracting the percentages of moisture, volatile matter and ash from the total sample composition of 100%. Essentially, the fixed carbon of a fuel is the percentage of carbon available for char combustion after all the volatile matter is removed from the biomass. This is not equal to the total amount of carbon in the fuel (the ultimate carbon) because there is also a significant amount released as hydrocarbons in the volatile matter. Fixed carbon gives a significant indication of the fraction of char that remains after the volatilization phase. These carbons will react with the oxygen to release heat [23]. The fix carbon values obtained in this study ranged from 29.1% for DP to 14.1% for SMC briquette (Figure 6). The amount of fix carbon decreases when the quantity of SMC increases because SMC has sand and soil which contribute to the significant proportions of fixed carbon [16].

3.2.5 Heating Value

The heating value is the standard measure of the energy content of a fuel. It is defined as the amount of heat released when a unit weight of fuel is completely burnt and the combustion products are cooled to 298K. The heating value of DP (5,880 cal/g) is higher than SMC (3,211 cal/g). The results show the trend of the heating value of SMC mixed with DP (Figures 7). The heating value drops when amount of SMC increases because the fixed carbon of DP is higher than SMC.

From the Figure 7, the briquette heating value of DP and Mix 4 sample is higher than compared to the lowest rank charcoal bar standard issued by the Thai community product standards charcoal bar 238/2547, the heating value of charcoal briquette should be equal to or higher than 5,000 cal/g [21]. This implied that DP and Mix 4 briquette have the potential product/source for use as household cooking fuel.

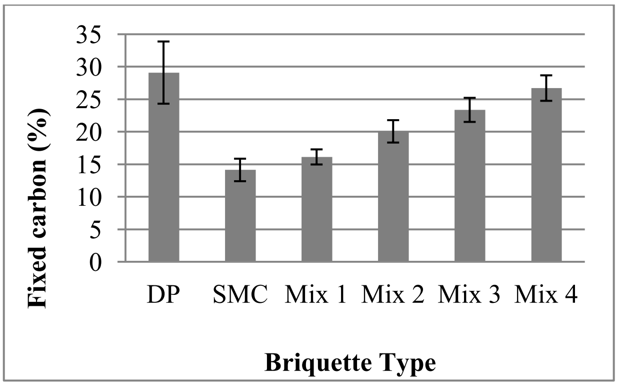

Fig. 6. Fixed carbon of briquettes.

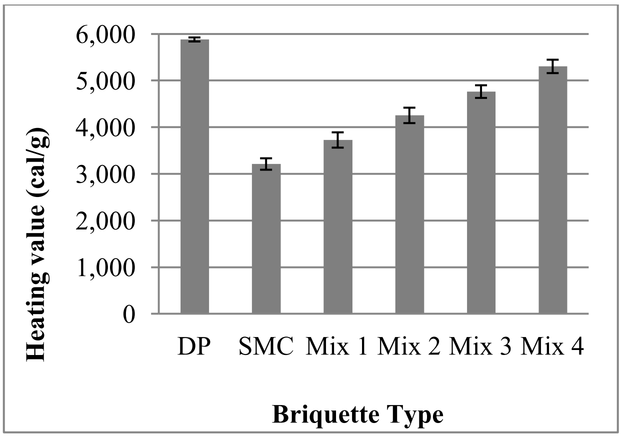

Fig. 7. Heating value of briquettes.

3.3 E

Cost analysis was carried out to check economic acceptability of briquetting by considering following assumptions:

1) A cost of one kilogram of biofuel briquette was 0.35 $.

2) An average inflation rate between year 2017 and 2018 was 1.1 %.
3) An interest rate was at 7%.
4) A capability of biofuel briquette production was 55.0 and 54.5 kg/day for DP and Mix 4 respectively.
5) A production process operates for 260 days a year.
6) A project lasts for 5 years.

3.3.1 Capital costs

Capital costs of a biofuel briquette from DP and Mix 4 be divided into two parts. The first part is an initial cost or a fixed cost including an extrusion machine, grinder, mixer and operating building. Total sunk cost was 4,800 $. Another part is a variable cost that the details were shown in Table 3. Table 4 shows input requirements for various briquette; production level, fixed and variable costs.

3.3.2 Return on Investment

All economic indications for different biomass briquetted fuel as IRR, PBP and NPW are summarized in Table 5. It was observed that IRR was 23.8 and 18.3 for DP and Mix 4 respectively while its NPW was 2,164.4 $ compared favorably with that for Mix 4 which was 1,382.4 $. The variation in IRR could be attributed to the type of feedstock used. These values are considered higher than the discounted rate adopted by banks in Thailand and giving indication that the project profitable. PBP of the plant was 2.7 and 3.1 years for DP and Mix 4 respectively and after that the unit will produce a net profit.

Table 3. Cost of installation of briquetting plant from Mix 4 and DP.

No.	Item	DP briquettes			Mix 4 briquettes		
		Quantity	Rate	Cost ($)	Quantity	Rate	Cost ($)
1	Cost of electricity	12 month	6 $/month	72	12 month	6 $/month	72
2	Maintenance cost		10% investment	480		10% investment	480
3	SMC	-	-	-	8.83 ton	33 $/ton	291.4
4	DP	42.04 ton	16.5 $/ton	693.7	33.63 ton	16.5 $/ton	554.9
5	cassava powder	715 kg	0.33 $/kg	235.9	707 kg	0.33 $/kg	233.3
6	Labor cost	260 day	5.3 $/day	1,378	260 day	5.3 $/day	1,378
7	tap water	1 year	7.3 $/year	7.3	1 year	7.3 $/year	7.3
8	Others cost			397			397
		Total		3,263.9			3,413.9

Table 4. Input requirements for each scenario.

Item	DP	Mix 4
Production level (kg/day)	55.0	54.5
Fixed costs ($)	4,800	4,800
Variable costs per unit ($/kg)	0.228	0.241

Table 5. Return on investment for each scenario.

Item	DP	Mix 4
Production level (kg/day)	55.0	54.5
Fixed costs ($)	4,800	4,800
Variable costs per unit ($/kg)	0.228	0.241

4. CONCLUSION

The study examined the physical properties of briquettes produced from DP and SMC as well as heterogeneous combination of the particles. The study affirmed that briquettes produced from DP and Mix 4 (mixture of DP and SMC char produced at 80:20) had better quality in terms of combustion properties with respect to high volatile matter, low ash content, high fixed carbon and high heating value. According to the Thailand bio-fuel briquette standard, heating value higher than 5,000 cal/g and moisture content lesser than 8% are accepted. Moreover, PBP with less than four years can be accomplished. This study has been able to confirm that agricultural wastes alongside wood waste can be utilized in producing quality briquettes. As such, DP and Mix 4 were suitable for briquette production due to better combustion performance.

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