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Utilization Biomass and Coal Mixture to Produce Alternative Solid Fuel for Reducing Emission of Green House Gas

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***Abstract*— This paper presents the characteristics of bio-briquette resulted from a series process using a mixture of raw materials. As raw materials of biobriquette production, this research used biomass corn cobs and banana peels, and a fine coal waste. Before using as a component in the biobriquette, corn cobs, banana peels, and fine coal waste were carbonized. The carbonation process was carried out in temperature of 300-500°C for 15 minutes. Carbonized corn cobs, banana peels, and a fine coal waste were characterized for calorific value and ash content. In this work, the influence of composition carbonized biomass and carbonized coal has been investigated. Before and after carbonization of biomass and coal, the calorific value and ash content of corn cobs were 4,239-6,386 kcal/kg and 3.47-8.12 % adb respectively, for banana peels were 4,135-6,042 kcal/kg and 16.99-32.31 % adb respectively, and for coal were 5,857-6,330 kcal/kg and 5.81-6.64 % adb respectively. The highest calorific value of biobriquette of 6,297 kcal/kg, highest fixed carbon content of 62.62 %, lowest volatile matter content of 26.18 % adb, lowest inherent moisture content of 5.14 % adb and lowest ash content of 6.06 were measured for composition of carbonized coal, carbonized corn cobs and carbonized banana peels ratio was of 1:4:0.**

***Keywords*— banana peels; biobriquette; carbonization; corn cobs; fine coal waste**

I. INTRODUCTION

Energy used Indonesian people today are mostly derived from fossil fuels, such as gas and oil fuel, and coal. A disadvantage of the use of fossil fuels is to damage the environment and also considered as a non-renewable and unsustainable. Coal is an alternative energy source than petroleum, coal consumption in the country is the biggest to the needs of power plants, while for other industries such as cement, steel, and small industry is still relatively small. Indonesian coal production and consumption will continue to increase in line with economic growth and energy needs.

Energy is very important factor in economic development of a country. Energy use in the world is increasing very rapidly. This condition can be considered as creating markets continue to grow. The world will continue to supply energy demand, and consequently, the investors and governments should explore a solution such as increasing efficiency and also generate renewable energy [1].

The energy consumption in the world has increased rapidly from 456.5 quadrillion Btu to 558.7 quadrillion Btu in the last decade. In the world's total natural gas, coal, oils, renewable and nuclear consumption increases by 1.7, 1.3, 1, 4.6 and 0.5 percent per year on average respectively [2]. An economic growth and increasing population quantity will also increase in demand of using energy. Utilization energy resources have environmental impacts, through raw materials exploitation, production, manufacturing, distribution, usage, and disposal [2].

Briquettes of biomass (or biobriquette) are frequently produced and used as energy in the household for cooking. It may also use for bricks and bakery industries. A various process can be carried out to produce the bio-briquettes using waste biomass.

Used as fuel, a briquette is a block of flammable matter for starting and maintaining a fire. Some types of briquettes are produced as charcoal briquettes and biomass briquettes [4]. In some countries, biomass briquette has obtained a very large quantity and used a large portion of cooking fuel needs of rural people. Some biomass likes rice straw, rice husk, corn cobs were used as raw material produce briquettes by the process of extrusion.

The briquette has many advantages compared to others solid fuels. There are [5]; (a) the price of briquettes is cheaper than coal, (b) oil, coal or lignite, once used, cannot be replaced (non-renewable), (c) in briquettes, there is no sulphur, so it does not pollute our environment, (d) practically, biobriquette has a higher calorific value, (e) ash content in briquettes is much lower about (2-10% as compared to 20-40% in coal), (f) compared to coal, combustion of biobriquette is more uniform, (g) briquettes are usually produced near consumer and supplies do not depend on erratic transport from long distances, and (h) due to low moisture content and higher density, biobriquettes give much higher boiler efficiency.

In South Sumatera Province, there are huge deposits of coal. This coal, especially lignite (low-rank coal) can be converted to briquette. In this province, many kinds of biomass waste can be obtained, as resulted from agriculture (such as rice, corn, banana, etc.) from plantation/estate industries (palm, rubber, wood, etc.). As assuming that 1 kg dry rice contain 300 gram husk giving the husk, while one kg corn contains corncob and corn tree as 5 kg giving biomass from corn. It indicates biomass from rice husk and corn cobs are potential as biobriquette [6]. From the banana tree, banana peels are one of kind of biomass waste and also can be used as raw material in biobriquette production.

Some researchers have investigated to produce briquette or biobriquette by using biomass and coal or by biomass-biomass mixture and biomass-coal mixture. Reference [2] have published that biobriquette can be produced by using cotton dust mixture with wood dust as raw material. In this study some various ratios of cotton dust:wood dust:starch:water were investigated. The biobriquette made with a ratio of 4:16:20:60 (%w) gave the highest heat energy of 3,960 kcal/kg. This experiment showed that cotton dust could be used as a component for biobriquette. Utilization of fine coal waste as fuel briquettes has been studied [7]. In this study, a pilot plant for fine coal processing to produce alternative fuel was carried out. A fine-grained waste generated in the processing plant of a coal-processing plant was utilized to produce briquettes. The briquette was made for three types of coal-based fuel briquettes with an addition biomass such as potato starch, molasses, and wood biomass. The results showed that briquettes made with starch met the minimum quality requirements, but the use of a cheaper binder (molasses) did not provide good quality briquettes. According to the results, a suitably high-energy value (22–24 MJ/kg) of the briquette was obtained and can be used as an alternative fuel for combustion in industrial and domestic boilers. Reference [8] have studied on biomass and plastics conversion to produce solid fuel briquettes. This experiment determines the briquettes production use from biomass in combination with plastic materials from different sources for the household. The briquettes combustion characteristics were studied. This study concluded that the geometry of the briquettes has no influence on the smoke emissions. In the combustion of this briquette, the behavior of combustion was steadier when the amount of polyethylene terephthalate (PET) in the briquettes was small, because of the increase of oxygen supply. In addition, the burning of the plastic in the mixture with biomass increases the carbon monoxide emissions from 10% to 30% as compared to carbon monoxide from sawdust biomass emissions used as a reference.

The fuel briquette from biomass–lignite blends was also subjected to study [9]. In this study, coal (lignite) was blended with some biomass (molasses, pine cone, olive refuse, sawdust, paper mill waste, and cotton refuse). This blend was used in the production of fuel briquettes. The briquetting pressures were applied between 50 and 250 MPa, and the ratio of biomass to lignite was changed between 0 and 30 % w. This study showed that the mechanical strength of the briquettes produced from lignite could be increased by adding some biomass samples. Water resistance of the briquettes can be increased by adding olive refuse, cotton refuse, and a pine cone or paper mill waste. Some factors influencing the performance of coal briquettes have been published [10]. The utilization of empty fruit fibre and palm shell to produce briquette as a renewable energy fuel was also studied. In this study, empty fruit bunch and palm shell were mixed in certain ratios. The mixture was densed into biobriquette at high pressure [11]. This work showed that the average calorific values for mixture ratios of 20-60% are range from 17,995-18,322 kJ/kg. For the same ratios, the specific densities are from 1,179-1,225 kg/m^{-3}. Utilization and management of biomass energy resources were also published [12]. This article discusses a comprehensive review of biomass energy sources, environment and sustainable development, present and future use of biomass as an industrial feedstock for production of fuels, chemicals, and other materials. The results of the study suggest that technology of biomass must be developed. The combustion of moist coal briquettes has studied [13]. The study found that compressive strengths of the moist coal briquettes in the horizontal and vertical directions were 37.0-70.0 kN/m^2 and 360.8-1,052.0 kN/m^2 respectively. An increase in moisture content was causing a decrease in compressive strength. The increasing of moisture content may lead to an increase in ignition time of the coal briquettes. Otherwise, the ignition time decreased as the ignition temperature increased. It was found that the combustion of the moist coal briquettes is the first order of all moisture contents (10-30 wt%). The combustion rate and the rate constant of coal briquettes combustion were determined. Utilization of the agricultural residues as a biomass briquetting for an alternative source of energy has been studied and published [14]. This paper discussed that agricultural wastes can be recycled and can be converted to the high density fuel biobriquettes without the addition of any binder. The biomass as a raw material such as sawdust, rice husk, coffee husk, cotton stalks, and ground nutshell, etc. were densified into biobriquettes at high pressure and temperature by using different technologies. Some various advantages factors that are affecting the biomass briquetting and comparison between coal and biomass briquetting were discussed. The combustion characteristics of compressed pulverized coal-rice husk briquettes have been determined [15]. In this research, the optimal compositions of coal, rice husk and palm oil sludge for energy derivation produced were studied at various compression pressures in the range of 20 to 45 Mpa. This work also investigated the combustion characteristics.

The results show that a 5:3:1 ratio by weight of coal, rice husk, and palm oil sludge. The optimum energy formulation of coal, rice husk, and palm oil sludge was obtained at a ratio of 5:3:1 with a calorific value of 19.97 MJ/kg. Rice straw and coconut shell were used to produce biobriquette [16]. This study showed that the calorific value of rice straw and coconut shells are 1,525.5kcal/kg and 7,283.5 kcal/kg respectively. The fixed carbon of rice straw and coconut shells are 15.61% and 78.32 % respectively. The calorific value of biobriquette in the ratio of rice straw/coconut shell as 50:50 is 4,354.5 kcal/kg. Reference [17] has reported that almost all of the biobriquetting technologies have been introduced in Nepal. Research and Development institutions have emerged, and research and development activities to support biomass briquetting are constantly increasing. The concept of utilizing waste for energy is increased by making briquettes competitive; with the increase in awareness about briquettes as a renewable source of energy. Development of technological capability in fabrication, reproduction, repair, and maintenance has been realized. The properties of briquettes produced from corn cobs and rice husk residues as reported in [18]. The ultimate and proximate analyses were conducted to determine the average composition of their constituents. The results of this study indicate that briquettes produced would make good biomass fuels.

The corncob briquette has more positive attributes of biomass fuel than rice husk briquette. The moisture content of corn cobs briquette was of 13.47%, higher density of 650 kg/m^3 and lower relaxation ratio of 1.70. Moreover, the corn cobs briquette has a higher volatile matter of 86.53%, the higher heating value of 20,890 kJ/kg and compressive strength of 2.34 kN/m2 compared to rice husk which is 67.98%. The results of research in a pilot test of fine coal processing to produce of solid fuel as reported by [19]. Fine-grained waste generated in the plant processing of Bogdanka coal mine (Lublin Coal Basin). There was taken for examination. In this study, the processes of material homogenising, the selection of the parameters in the roll press unit and the quality of the briquettes analyses were carried out. This work was used the existing technological line the pilot series of fuel briquettes with binders of potato starch and molasses. The briquette fuel has a value of energy that great enough in order to be used as the alternative fuel to the burn in industrial boilers and in residential as well.

II. Material and Method

A. Raw Material

The biomass waste materials used in the study were hybrid yellow corn cobs and banana peel that were collected from the traditional market at Palembang, while coal was collected from PT Bukit Asam Kertapati Pier Unit (Persero), Tbk. An adhesive material was of starch solution.

B. Equipment Used

Equipment used: (1) jaw crusher, (2) rotary sample divider, (3) double roll crusher, (4) drying oven, (5) analytical balance, (6) ash furnace (carbolite), volatile furnace (carbolite), (7) bomb calorimeter, (8) briquette press devices.

C. Carbonization of Raw Material Procedure

The carbonization process of raw material was carried out as following steps:

- Coal was crushed in order to get the size of material became small and to facilitate carbonization in furnaces.
- Coal was then destroyed entered into a porcelain dish and weighed with an analytical balance.
- Coal was carbonized using a furnace with a variable temperature (300°C, 350°C, 400°C, 450°C, 500°C) for 15 minutes of carbonization.
- Carbonized coal then was mixed, crushed and sieved to 30 mesh sieve numbers so that the resulting carbonized coal powder in accordance with the powder particle size desired.
- Carbonized coal that has been prepared was analyzed by proximate analysis test.
- Carbonization of corn cobs and banana peels were carried out at a variable temperature (300°C, 350°C, 400°C, 450°C, 500°C) for 15 minutes of carbonization.
- Carbonized-corn cobs and carbonized-banana peels then were crushed and sieved to 30 mesh sieve.
- Finally carbonized material mixture was mixed to produce a biobriquette by the addition of starch solution. The mixture ratio of carbonized material (%w) in biobriquette (coal:corn cobs: banana peels) is presented in Table 1.
- Then, this biobriquette was analyzed to know the quality of biobriquette such as calorific value (ASTM D 5865 2010), inherent moisture, IM (ASTM D 3173 2009), volatile matter, VM (ASTM D 3172 2009), ash (ASTM D 3174 2009) and fixed carbon (100-IM-Ash-VM)

TABLE I
Composition of Raw Carbonized Material (%W) in Biobriquette (Coal:Corn Cobs:Banana Peels)

Composition	Composition code
20:80:00	A
20:70:10	B
20:60:20	C
20:50:30	D
20:40:40	E
20:30:50	F
20:20:60	G
20:10:70	H
20:00:80	I

III. Results and Discussion

A. Characterization of Raw Material Before Carbonization

Table 2 as below represents calorific value (kcal/kg), inherent moisture (% adb), ash content (% adb), volatile matter (% adb), and fixed carbon (% adb) of corn cobs, banana peels, and fine coal waste before carbonization process. Before carbonization, the calorific value of corn cobs, banana peels and fine coal waste were of 4,239 kcal/kg, 4,452 kcal/kg and 5,857 kcal/kg respectively. The inherent moisture of corn cobs, banana peels, and fine coal waste were of 5.01 % adb, 7.12 % adb, and 10.80 % adb respectively. The ash content of corn cobs, banana peels, and fine coal waste were of 3.47 % adb, 17.00 % adb, and

5.81 % adb respectively. The volatile matter content of corn cobs, banana peels, and fine coal waste were of 70.64 % adb, 64.61 % adb, and 38.58 % adb respectively. The fixed carbon of corn cobs, banana peels, and fine coal waste were of 20.91 % adb, 11.27 % adb, and 44.81 % adb respectively.

TABLE II
CALORIFIC VALUE, INHERENT MOISTURE, ASH, VOLATILE MATTER AND FIXED CARBON BEFORE CARBONIZATION OF CORN COBS, BANANA PEELS AND COA

Materials	Calorific value (kcal/kg)	IM % (adb)	Ash % (adb)	VM % (adb)	FC % (adb)
Corn cobs	4.239	5.01	3.47	70.61	20.91
Banana peels	4.452	7.12	17.00	64.61	11.27
Coal	5.857	10.80	5.81	38.58	44.81

B. Characterization of Raw Material after Carbonization

1) Calorific Value: Fig. 1 represents the calorific value (kcal/kg), of corn cobs, banana peels and fine coal waste after carbonization process at 300, 350, 400, 450 and 500 °C. After the carbonization process, the calorific value of coal, corn cobs and banana peels were increased at the temperature of 300°C to 500°C. The highest calorific value of 6,386 kcal/kg of carbonized corn cobs was measured at a temperature of 500°C. The highest calorific value of 6,042 kcal/kg of carbonized banana peels was obtained at a temperature of 300°C, and for carbonized fine coal waste at 500°C, the calorific value was of 6,330 kcal/g.

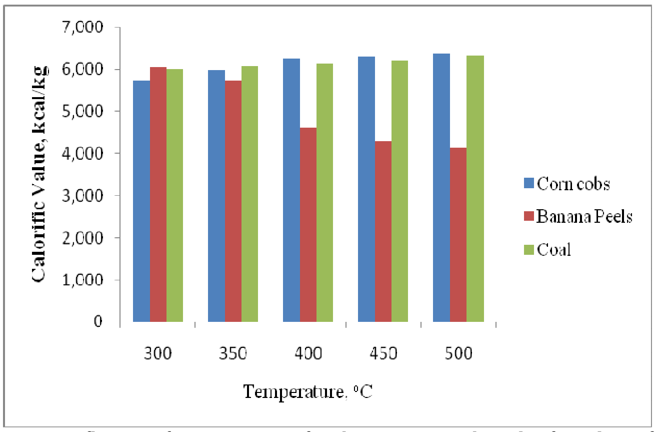

Fig. 1 Influence of temperature of carbonization on the calorific value of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste

The calorific values for carbonized corn cobs and carbonized fine coal waste were increased with increasing of carbonization temperature. But, for carbonized banana peel, the calorific value was decreased with increasing of carbonization temperature range from 300°C - 500°C. At a temperature of 300°C, banana peels are already carbonized perfectly and in increasing of temperature of carbonization. According to Indonesian Standard of briquette SNI No. 1/6235/2000, the calorific value is ≥ 5,000 kcal/kg. This result indicates that all carbonized material was met to the standard, except carbonized banana peels obtained at carbonization temperature at 400, 450 and 500 °C. The high number of calorific value content fuel in combustion influenced enhancing high temperature.

2) Inherent Moisture: Fig. 2 represents the inherent moisture (% adb) of corn cobs, banana peels, and fine coal waste after carbonization process at 300, 350, 400, 450 and 500 °C. Before carbonization, the inherent moisture of corn cobs, banana peels, and fine coal waste were of 5.01 % adb, 7.12 % adb, and 10.80 % adb respectively and after the carbonization process, the inherent moisture of coal, corn cobs, and banana peels were decreased at the temperature of 300°C to 500°C. The highest inherent moisture of carbonized corn cobs, carbonized banana peels, and carbonized fine coal waste were of 4.1 %, 6.53 %, and 9.11 % respectively. These inherent moisture content are less than the standard value of 8 % (SNI No. 1/6235/2000).

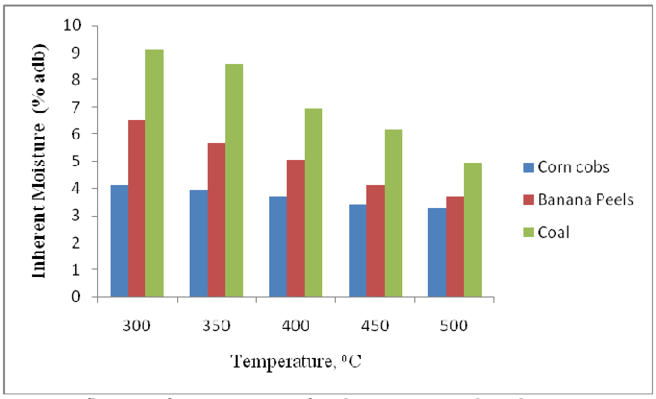

Fig. 2 Influence of temperature of carbonization on the inherent moisture of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste

3) Ash Content: Fig. 3 represents the ash content (% adb) of corn cobs, banana peels, and fine coal waste after carbonization process at 300, 350, 400, 450 and 500 °C.

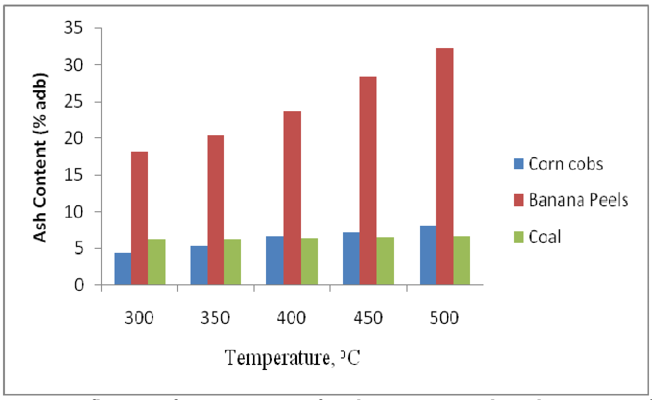

Fig. 3 Influence of temperature of carbonization on the ash content of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste

The ash content of corn cobs, banana peels, and fine coal waste before carbonization were of 3.47 % adb, 17.00 % adb, and 5.81% adb respectively and after the carbonization process at the temperature of 300°C to 500°C, the ash content of coal, corn cobs, and banana peels were increased. The highest ash content of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste were of 8.12 % adb, 32.31% adb and 6.64 % adb when carbonization was carried out at a temperature of 500 °C. According to standard, ash content is ≤ 8 % (SNI No. 1/6235/2000). The ash content of all carbonized coal are matched with it standard value, but the ash content of all carbonized banana peels are not matched with it standard value. The ash content of all carbonized corn cobs is match with it standard value except for carbonization at 500 °C.

4) Volatile Matter : Fig. 4 represents the volatile matter (% adb) of corn cobs, banana peels and fine coal waste after carbonization process at 300, 350, 400, 450 and 500 °C. The volatile matter of corn cobs, banana peels, and fine coal waste before carbonization were of 70.61 % adb, 64.61 % adb, and 38.56 % adb respectively. After the carbonization process at the temperature of 300°C to 500°C, the volatile matter of coal, corn cobs and banana peels were decreased. The highest volatile matter of carbonized corn cobs, carbonized banana peels, and carbonized fine coal waste were of 41.40 % adb, 48.27 % adb and 38.17 % adb respectively when carbonization was carried out at a temperature of 300 °C.

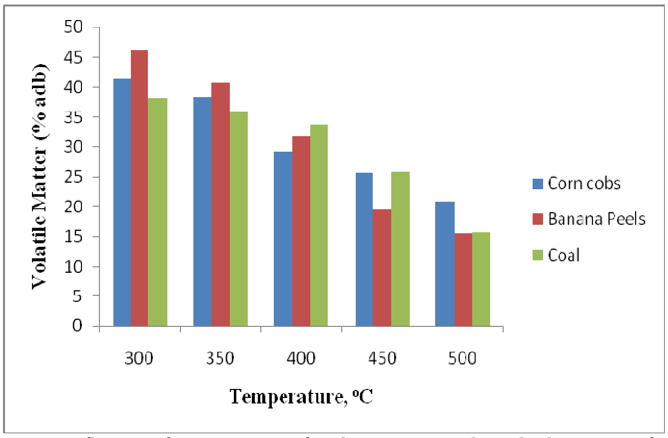

Fig. 4 Influence of temperature of carbonization on the volatile matter of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste

5) Fixed Carbon : Fig. 5 represents the fixed carbon (% adb) of corn cobs, banana peels and fine coal waste after carbonization process at 300, 350, 400, 450 and 500 °C. The standard value of fixed carbon is ≥ 77 % (SNI No. 1/6235/2000). while fixed carbon content of corn cobs, banana peels, and fine coal waste before carbonization were of 20.91 % adb, 11.27 % adb, and 44.81 % adb respectively. After the carbonization process at the temperature of 300°C to 500°C, the fixed carbon of coal, corn cobs, and banana peels were increased. The highest fixed carbon content of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste were of 67.70 % adb, 48.47 % adb and 72.8 % adb when carbonization was carried out at a temperature of 500 °C. The fixed carbon content of all carbonized coal are not matched with it standard value, but the ash content of all carbonized banana peels are not matched with it standard value. From the analysis, it can be considered that the optimal temperature for the carbonization of corn cobs and coal are at 500°C and for a banana peels is at 300°C.

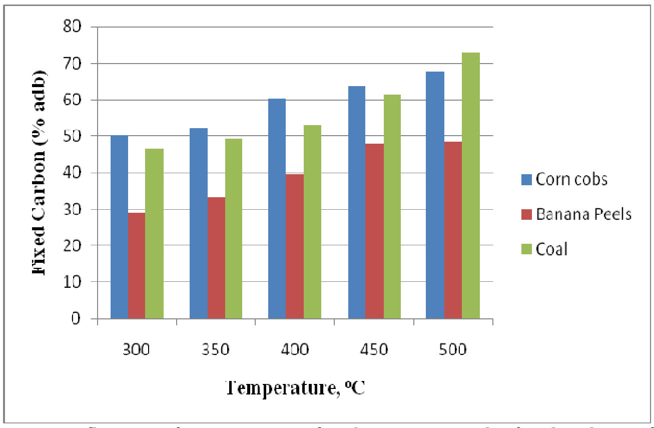

Fig. 5 Influence of temperature of carbonization on the fixed carbon of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste

C. Characterization of Raw Biobriquette.

1) Calorific value : The Fig. 6 represents the influence of the composition of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste on the calorific value of biobriquette. This Fig. 6 shows that, if the percentage of carbonized banana peels and carbonized corn cobs ratio was increased, the calorific value of biobriquette was decreased from 6,297 to 5,126 kcal/kg.

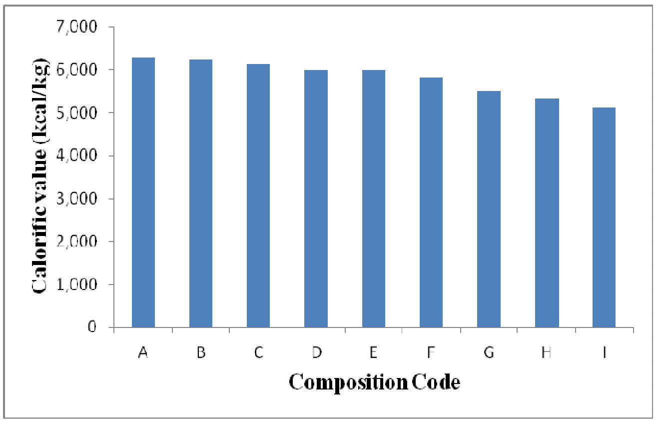

Fig. 6 Influence of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste composition (%w/w) on calorific value of biobriquette

The decreasing of the calorific value of this biobriquette was caused by calorific value of banana peels less than the calorific value of corn cobs. These calorific value of all biobriquette composition were higher than standard calorific ≥ 5,000 kcal/kg. The highest calorific value of biobriquette of 6,297 kcal/kg was obtained for the composition of carbonized coal, carbonized corn cobs and carbonized banana peels ratio was of 20:80:00.

The calorific value of all biobriquette produced in this work is higher than that biobriquette produced by the work published in [2]. The calorific value of bio-briquette was 3,960 kcal/kg for ratio of cotton dust : wood dust : starch : water as 4:16:20:60 (% wt) [2]. The calorific value of all biobriquette produced in this research is also higher than biobriquette made from sawdust with the addition of 30 % paper binder and 30 % wheat flour binder having 4,333 kcal/kg and 4,786 kcal/kg respectively [3]. The biobriquette with 75% corncob and 25% husk gave the calorific value of 5,331.95 kcal/kg [6]

2) Inherent Moisture : The Fig. 7 shows the influence of the composition of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste on the inherent moisture content of biobriquette. If the percentage of carbonized banana peels and carbonized corn cobs ratio was increased, the inherent moisture of biobriquette was increased from 5.14 % to 8.82 %. The increasing of inherent moisture of this biobriquette was caused by the inherent moisture of banana peels higher than inherent moisture of corn cobs. This inherent moisture of all biobriquette composition were matched with standard ≤ 8 %, except for carbonized banana peels and carbonized corn cobs ratio more than 50:30.

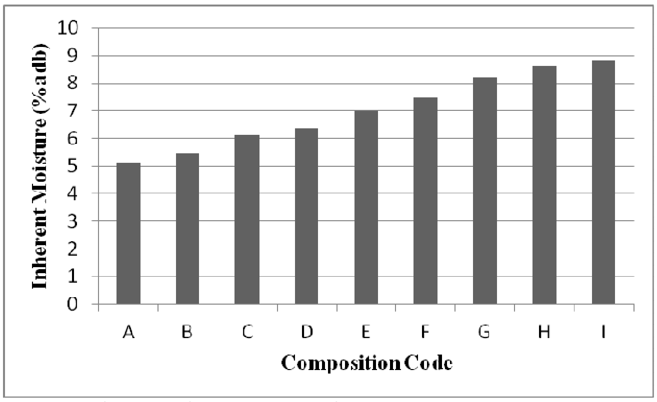

Fig. 7 Influence of composition of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste on inherent moisture content of biobriquette

3) Ash Content : The Fig. 8 shows the influence of the composition of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste on ash content of biobriquette. This Fig. 8 represents the percentage of carbonized banana peels and carbonized corn cobs ratio was increased, the ash content of biobriquette was increased from 6.06 % to 16.82 %. The increasing of the ash content of this biobriquette was caused by ash content of banana peels higher than ash content of corn cobs. These ash content of all biobriquette composition were matched with standard ≤ 8 %, except for carbonized banana peels and carbonized corn cobs ratio more than 10:70.

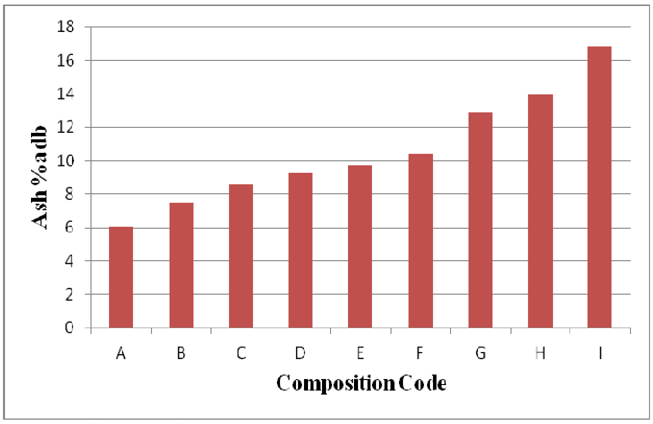

Fig. 8 Influence of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste composition on ash content of biobriquette

4) Volatile Matter : The Fig. 9 indicates the influence of the composition of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste on volatile matter content of biobriquette. Increasing of carbonized banana peels and carbonized corn cobs ratio, the volatile matter content of biobriquette increased from 26.18 to 42.2 % adb. The increasing of volatile matter of biobriquette was influenced by volatile matter content of banana peels higher than volatile matter content of corn cobs.

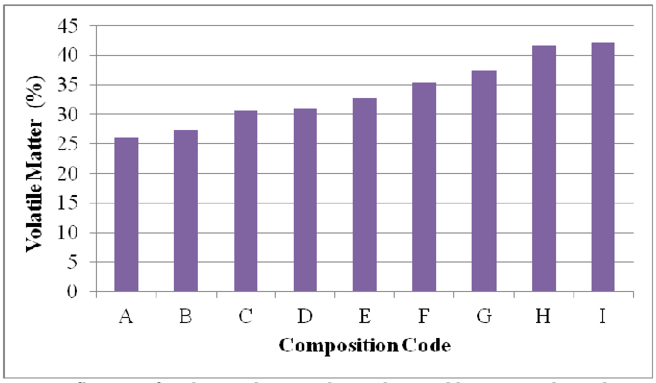

Fig. 9 Influence of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste composition (%w/w) on volatile matter content of biobriquette

5) Fixed Carbon : Influence of carbonized corn cobs, carbonized banana peels ratio in biobriquette on fixed carbon content is presented in Fig. 10 as following. Fig. 10 represents an increase of carbonized banana peels and carbonized corn cobs ratio, while the fixed carbon content of biobriquette was decreased from 62.62 to 32.16 % adb. The decreasing of fixed carbon content of biobriquette was caused by fixed carbon content of banana peels less than fixed carbon content of corn cobs. These fixed carbon contents of all biobriquette composition did not match to the standard (≥ 77 %).

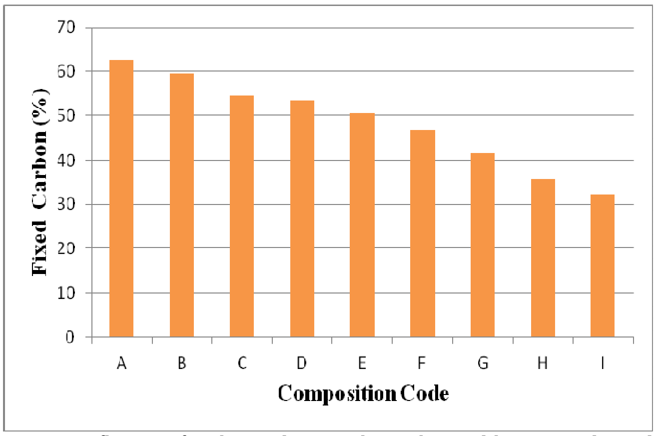

Fig. 10 Influence of carbonized corn cobs, carbonized banana peels and carbonized fine coal waste composition on fixed carbon content of biobriquette

IV. CONCLUSION

After the carbonization, the calorific value of coal, corn cobs and banana peels were increased, but for the banana peel, the calorific value was decreased with the increasing of carbonization temperature range from 300^oC - 500^oC.

The highest calorific value of 6,386 kcal/kg of carbonized corn cobs was measured at a temperature of 500^{o}C. The highest calorific value of 6,042 kcal/kg of carbonized banana peels was obtained at a temperature of 300^{o}C, and for carbonized fine coal waste at 500^{o}C, the calorific value was of 6,330 kcal/g.

The percentage of carbonized banana peels and carbonized corn cobs ratio was increased, the calorific value of biobriquette was decreased. The highest calorific value of biobriquette of 6,297 kcal/kg was obtained for the composition of carbonized coal, carbonized corn cobs and carbonized banana peels ratio was of 20:80:00. In general calorific value of all biobriquette composition were higher than standard calorific ≥ 5,000 kcal/kg. It is recommended that in the future research, characterization of flue gas of biobriquette combustion should be measured.

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