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Experimental Investigation on Combustion of Bio-Pellets from Indonesian Cocoa Pod Husk

[1]M. Syamsiro, [2]H. Saptoadi and [3]B.H. Tambunan
[1]Department of Mechanical Engineering, Janabadra University, Yogyakarta 55231, Indonesia
[2]Department of Mechanical and Industrial Engineering, Gadjah Mada University, Yogyakarta 55281, Indonesia
[3]Department of Mechanical Engineering, Medan State University, Medan 20221, Indonesia

Corresponding Author: Mochamad Syamsiro, Department of Mechanical Engineering, Janabadra University, Jalan TR Mataram 57 Yogyakarta 55231, Indonesia Tel: +62 274 543676 Fax: +62 274 543676

ABSTRACT

The objective of this study was to study the effect of wall temperature, preheated air temperature and dimension on combustion characteristics of bio-pellets from Cocoa Pod Husk (CPH). CPH was sun-dried, crushed and screened to obtain the particle size of less than 1 mm. Five grams mixture of CPH and binder with the composition of 70 and 30% weight, respectively was palletized and dried at 50°C for 5 h. The result shows that wall temperature and preheated air temperature significantly affected the mass losses of CPH. Temperature had obviously been a main driver for combustion process. Meanwhile, the wider surface area will apparently provide faster mass loss of the pellet. In contrast to the mass loss, CO emission factor was not significantly affected by wall temperature and preheated air temperature while the higher the ratio of surface area to pellet mass, the lower the CO emission factor. The study has identified that CPH had similar combustion characteristic compared with other biomass so that it is very potential as an alternative fuel for combustion system.

Key words: Cocoa pod husk, renewable energy, burning time, CO emission

INTRODUCTION

Now-a-days, Indonesia's energy consumption was dominated by petroleum-derived fuel. However, crude oil reserves (proven and potential) declined about 14.47% from 9.61 billion barrel in 2000 to 8.22 billion barrel in 2008 (MEMRI, 2008). Therefore, Indonesia has to accelerate the use of renewable energy sources, such as solar, wind, micro hydro and biomass. One of the renewable energy that has abundant potential is biomass. It is capable of displacing large amounts of solid, liquid and gaseous fossil fuels (Hassan *et al*., 2011). Utilization of biomass energy has long been carried out and it was the oldest energy that has a significant role, especially in rural areas. Biomass is usually available in the rural area and hence, by transforming and converting these sources of energy to power various processing machines, added value of agricultural products can be made (Demirbas, 2004). Biomass has been used for various purposes such as for household needs (cooking and household industry), drying of agricultural products, wood, ceramic, brick and tile, electric power generation in the sugar industry (MEMRI, 2004).

The fuel potential of biomass includes wood, short-rotation woody crops, wood waste, bagasse, sawdust, oil palm residue, corncob, rice husk, rice straw, waste from food processing and municipal solid waste. Extensive researches on biomass energy have been conducted by many researchers. Biomass offers important advantages as a combustion feedstock due to high volatility of the fuel and the high reactivity of both the fuel and the resulting char (Demirbas, 2004). One of biomass potential which has been unused, is Cocoa Pod Husk (CPH). It was the residues produced after removal of the cocoa bean from the fruit. Indonesia was the third largest producer of cocoa bean in the world, so that there are abundant CPH that is still being wasted. The utilization of the cocoa by-products, cocoa sweating and CPH, has been investigated by Agyeman and Oldham (1986). However, this study only discussed the chemical composition of CPH after ashing.

Biomass can be used as either an individual fuel or co-firing with coal. Co-firing has the capability to reduce both NO_x and SO_2 levels from existing coal fired power plant as well as CO_2 emission because biomass is a CO_2 neutral fuel (Narayanan and Natarajan, 2006). Co-firing of coal and rice husk has been investigated by Zakaria *et al.* (2010) and several co-firing projects have been summarized by Dai *et al.* (2008). Biomass particularly agricultural waste has low energy density and high moisture content, hence treatment process prior to combustion or gasification is an important way to enhance thermal efficiency of the systems. Drying of biomass is a very reasonable way of increasing the efficiency of heat and power generation, reducing emissions and improving the plant operation (Svoboda *et al.*, 2009). Compacting technology can also be used to improve its handling characteristics, enhances its volumetric calorific value, reduces transportation cost and produces a uniform, clean, stable for production of environment-friendly fuels (Demirbas and Demirbas, 2009; Wilaipon, 2007).

Conversion of biomass into useful forms of energy can be done by using a number of different processes. It can be converted into three main products, i.e. power/heat generation, transportation fuels and chemical feedstock (McKendry, 2002). Co-generation system producing heat and power was commonly used in some industries such as sugar cane factories (Ataei, 2009). Two main ways of converting biomass into energy are biochemical conversion and thermochemical conversion processes. Thermochemical conversion technologies include combustion, gasification and pyrolysis (Kumar *et al.*, 2009). Combustion is used over a wide range of outputs using various items of process equipment, e.g., stoves, furnaces, boilers, etc., (McKendry, 2002). Combustion model can be classified as macroscopic or microscopic. Biomass properties for macroscopic analysis, such as ultimate analysis, heating value, moisture content, particle size, bulk density and ash fusion temperature. Properties for microscopic analysis include thermal, chemical kinetic and mineral data (Ragland and Aerts, 1991).

The objective of this study was to study the effect of several parameters, i.e., wall temperature, preheated air temperature and dimension on combustion characteristics of bio-pellets from CPH.

MATERIALS AND METHODS

This study was performed from January to August 2007 where the sample CPH was collected from local cacao plantation. Research has been carried out by drying CPH under sunlight for three days. CPH then was crushed and screened to obtain the particle size of less than 1 mm. Five grams mixture of CPH and binder with the composition of 70 and 30% weight, respectively was palletized by using 16 mm diameter-mold palletizing machine and then dried in an oven at 50°C for 5 h. Proximate analysis of CPH is given in Table 1.

Combustion tests have been carried out in order to investigate the influence of wall temperature (experiment 1), preheated air temperature (experiment 2) and dimension (experiment 3) on the fuel combustion characteristics. The first experiment was conducted at constant air flow rate of

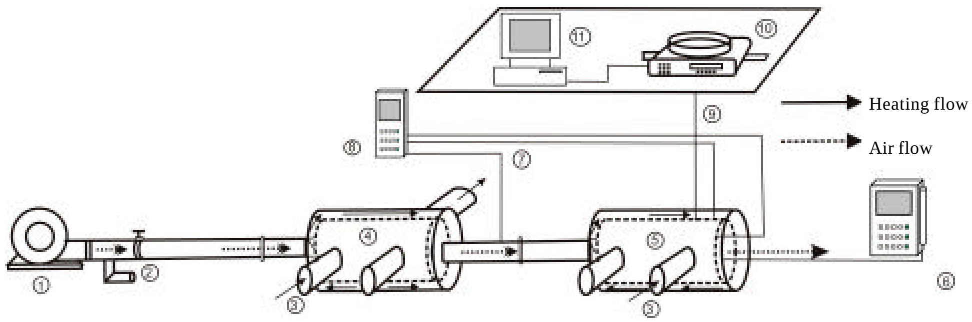

Fig. 1: A schematic diagram of combustion test. 1: Air fan, 2: Control valve, 3: LPG heater, 4: Air preheating chamber, 5: Combustion chamber, 6: Gas analyzer, 7: Thermocouple wire, 8: Digital thermocouple reader, 9: Wire hanger, 10: Digital balance, 11: Computer

Table 1: Proximate analysis of cocoa pod husk (% wt)

Samples	Cocoa pod husk
Moisture	16.1
Volatile matter	49.9
Fixed carbon	20.5
Ash	13.5
HHV (MJ kg^{-1})	17.0

0.3 m sec^{-1}. while the second experiment was performed at constant air flow rate of 0.3 m sec^{-1} and constant wall temperature of 350°C. Meanwhile we used three different diameter-mold palletizing machine, i.e., 13, 16 and 28 mm for third experiment. Photograph of different sizes of pellets can be seen in Fig. 1. Liquefied Petroleum Gas (LPG) was used as a heating source for supplying heat to the reactor. Schematic diagram of this study is shown in Fig. 1.

After reaching the expected wall temperature, the pellet is fed into the reactor and put on the cup which is hung with wire connected to a digital balance. Measurement of mass and CO emissions would be stopped, if the mass of pellet got a constant value which means the combustion was completed. Normalized mass of pellet can be obtained using the formula below:

$$\text{Normalized mass} = \frac{\text{Mass at given time}}{\text{Initial mass}} \tag{1}$$

Calculation of CO emission factor refers to the formula by Bhattacharya *et al.* (2002a).

RESULTS AND DISCUSSION

Effect of wall temperature: The effect of wall temperature on the mass losses of CPH is shown in Fig. 2. It can be seen that the increase of wall temperature decreased the drying time since the gas temperature increased. Theoretically, drying process is highly affected by temperature as the increase of temperature difference between pellet and gas increased heat and mass transfer from the pellet to gas. The higher the temperature of the gas, the faster the drying process. The shortest burning time occurred at wall temperature of 450°C as shown in Fig. 3. Burning time was mainly

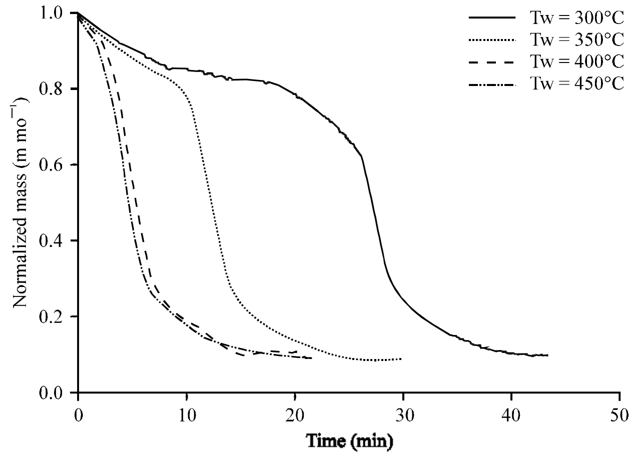

Fig. 2: Normalized mass versus time with different wall temperature

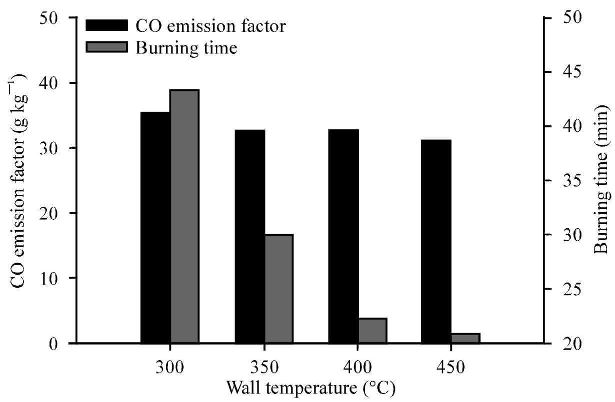

Fig. 3: CO emission factor and burning time of pellets under different wall temperature

affected by reaction temperature in the chamber. From Arrhenuis formula, we can see that reaction rate constant is affected by temperature. As temperature increases, there is a sharp rate of increase of reaction rate constant (El-Mahallawy and Habik, 2002).

Figure 3 also shows the effect of wall temperature on CO emission. The CO emission of CPH was indicated by emission factor which means the weight ratio of CO released to initial biomass. The wall temperature slightly affected CO released. It can be seen that the increase of wall temperature decreased the emission factor. The lowest emission factor occurred at the wall temperature of 450°C. The similar result has been reported by another researcher (Venkataraman and Rao, 2001) using dung cake as a fuel in various stoves. CO emission factor increased with decreasing combustion temperature.

Effect of preheated air temperature: The effect of preheated air temperature on the mass losses of CPH pellet is given in Fig. 4. The result shows that the increase of preheated air temperature accelerated the mass loss of pellet. The preheated air temperature of 80°C demonstrated the fastest mass loss of pellet. Figure 5 shows that burning time decreases as the increase of preheated air temperature. It is consistent with the experiment using corn straw in a fixed bed reactor as reported by Zhao *et al.* (2008) indicating that the average burning rate increased with increasing the

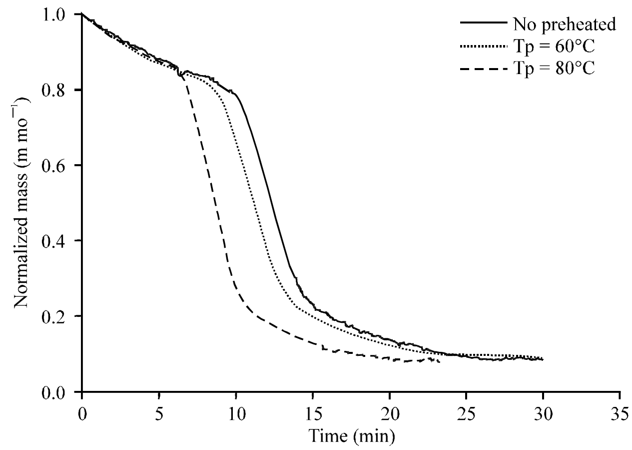

Fig. 4: Normalized mass versus time with different air temperature

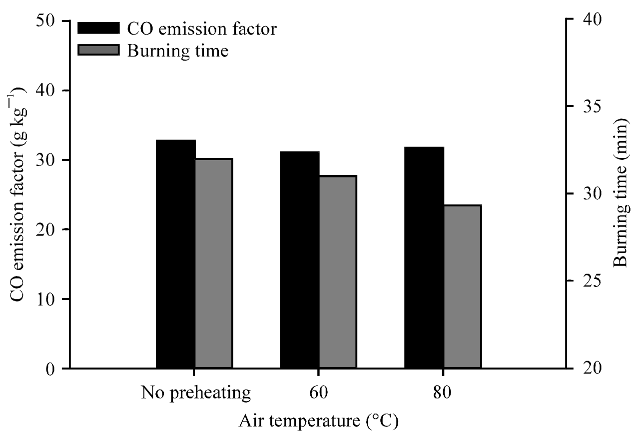

Fig. 5: CO emission factor and burning time of pellets under different air temperature

primary air preheating temperature. Air preheating is commonly done both to enhance the overall system efficiency and to increase the flame temperature. This can also be used to increase cumulative conversion efficiency in gasification process as hot air provides additional enthalpy necessary for reaction thereby decreasing the equivalence ratio (Kumar *et al*., 2008). Utilization of flue gas from combustion process is the common way for preheating air.

CO emission as the effect of preheated air temperature can be seen in Fig. 5. The air preheated temperature not significantly affected CO released. CO emission factor had similar value for different air temperature. Different result has been shown by Zhao *et al*. (2008). CO concentration with time was more intensive at higher primary air preheating temperature during the ignition front propagation period and the char oxidation period.

Effect of dimension: Figure 6 shows the effect of pellet dimension on the mass losses of CPH. The results show that pellet diameter of 16.3 mm produced the slowest mass loss of CPH. Higher diameter (28.3 mm) and lower diameter (13.3 mm) pellets provided faster mass losses of CPH. This occurred because the important parameter for combustion reaction is ratio of surface area to pellet mass. Based on this calculation, diameter of 16.3 mm has ratio of 4.68 cm g^{-2} while diameter of

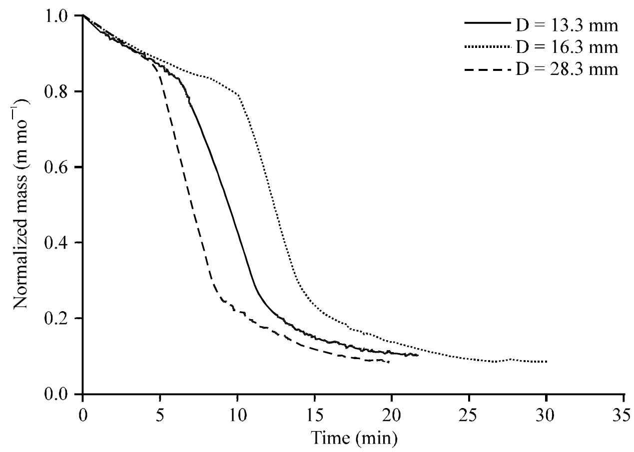

Fig. 6: Normalized mass versus time with different pellet diameter

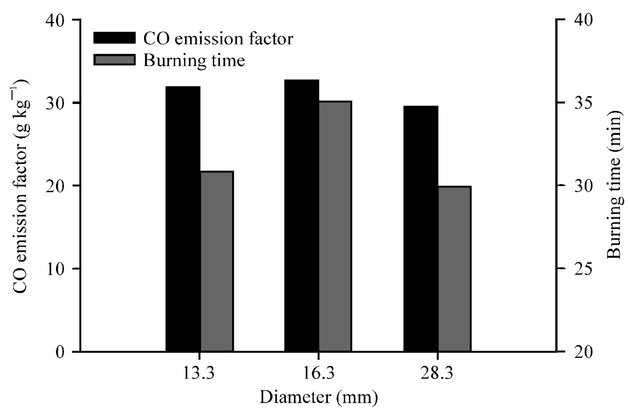

Fig. 7: CO emission factor and burning time of pellets under different diameter

13.3 and 28.3 mm have ratio of 5.13 and 5.92 cm g^{-2}, respectively. The wider surface area will obviously provide more surface contact between pellet and air, so that more reaction would be taken place. The same results were obtained by Saptoadi (2008) and Pambudi *et al.* (2010) using sawdust and jatropha cake seed as raw materials.

The CO emission of pellet combustion with different dimension is shown in Fig. 7. It shows that there is proportional relation between CO emission factor and burning time. CO emission factor would increase if burning time increased and vice versa. It also can be seen that the higher the ratio of surface area to pellet mass, the lower the CO emission factor. Bhattacharya *et al.* (2002b) reported similar result for combustion of wood block in various stoves.

CONCLUSIONS

Combustion characteristics of bio-pellets from Indonesian CPH have been experimentally investigated. The result shows that wall temperature and preheated air temperature significantly affected the mass losses of CPH. Temperature had obviously been a main driver for combustion process. Meanwhile, the wider surface area will apparently provide faster mass loss of the pellet. In contrast to the mass loss, CO emission factor was not significantly affected by wall temperature and preheated air temperature while the higher the ratio of surface area to pellet mass, the lower the CO emission factor. The study has identified that CPH had similar combustion characteristic compared with other biomass so that it is very potential as an alternative fuel for combustion system.

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