



CO-OXIDATIVE CHARACTERISTICS OF CORN COB WITH PLASTIC BAG AS AN ALTERNATIVE FUEL FOR POWER PLANTS

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ABSTRACT

Corn cob (CC) as an alternative fuel for the power plant is still under study, especially in Indonesia. In Indonesia, steam power plants are still using coal fuel in currently. This study was conducted to obtain co-oxidative characteristics of CC with plastic bag (PB) as an alternative fuel for power plants. Determination of the characteristics of CC with PB mixture as fuel is carried out in oxidative study. Test co-oxidative characteristics of CC with PB is conducted by a thermogravimetric analysis at heating rate of 10°C/min, nitrogen flow rate of 50 ml/min, and temperature from 30 - 800°C. The dehydration process occurs at temperatures from 40 - 100°C, while for thermal degradation at temperatures from 200 - 340°C, 400-500°C, and 580 - 670°C. Activation energy and calorific value of CC with PB mixture increase significantly with the addition of 10%, 30%, and 50% PB in CC. It is concluded that co-oxidative characteristic of CC with PB mixture is suitable and better as fuel for power plant if compared with its original state of CC.

Keywords: corn cob, co-oxidative, fuels, plastics bag, power plant.

1. INTRODUCTION

Indonesia is one of the developing countries in Asia experience rapid population growth, resulting in increased volume of municipal solid waste (MSW) and greater requirements of electrical energy. In addition, the other issue is that Indonesia experienced problems concerning shortages in electric energy. Generally, the average ratio had been about 76.96%. This suggested that an average of about 23.04% of people did not use electricity for daily use, especially in remote areas. In fact, the West and the East Nusa Tenggara had an average ratio of approximately 41 - 60%, while in West Papua, the approximate percentage was very low with only 34.62% in 2012 [1].

In 2010, the Western and the Eastern Indonesia experienced electric energy crisis due to the limited capacity of energy plants for PT. PLN (Persero) in producing electricity. Moreover, the national electrification ratio (NER) and the availability of electrical energy had been low, especially outside Java, averaged below 65%. Besides, the NER was varied for each province in Indonesia. It was generally around 40% to 60%, but four provinces only had about 20% - 40% [2]. Many people in the rural areas did not use electricity, while in urban areas, blackouts occurred frequently. This was due to the limited capacity of power plants to meet the increasing demands of society and industry. This suggested that the availability of electricity in Indonesia was still lacking. In fact, the projection of electric energy in Indonesia in the period 2010 - 2019 has been to increase by an average of 12.25% per year. Thus, on average, the need for fuels increases annually, i.e. about 17.8% for coal, 16.8% for LNG, and 1.5% for gas [2].

The composition of MSW consists of food scraps, yard, paper, wood, textile, glass, metal, cardboard,

plastics, tire, organic matter, as well as other wastes [3-5]. The disposal of MSW can cause stratospheric ozone depletion, acid levels increase, the greenhouse effect, the critical toxicity, and physical disorders [6]. Apart from that, developing countries also do experience issues related to electric energy needs. This is because; increased energy needs are in line with population growth, economic boost, and industrial progress. For instance, Indonesia increases its electrical energy needs at an average of 12.25% annually to support the demand for energy due to growth in population, economic, and industry [7].

Plastic solid waste (PSW), specifically for PB basically has the economic potential and is a source of livelihood for the poor. Thereafter it decomposes, the plastic becomes a source of pollution in water and soil, and the air of combustion. Plastic in the open combustion can produce toxic gases. These gases can be a cause of hepatitis, cancer, affects the nervous system and liver. However, if left on landfill MSW, PSW can produce greenhouse gases that damage the environment [8]. Nevertheless, the use of plastic bags in Indonesia cannot be avoided and there is no alternative materials which can be used by the public for day-to-day activities. PSW has the potential energy with high calorific value (CV) compared to biomass fuel. Therefore, some countries have made use of the PSW as fuel in power plants [9]. The utilization of PB as fuel in boilers, the exhaust emissions can be minimized by using exhaust emission control system [10]. Incineration waste to energy method is an appropriate method for overcome MSW because it can minimize the volume of MSW by 90% [11] and the weight of MSW by 75% [9]. In addition, the energy yields every 1000 kg of MSW incineration can be generate electric energy around 0.5 MWh and minimize the exhaust gases of combustion [12]. Therefore, it can help conserve



landfill significantly, overcome the electrical energy crisis, and reduce environmental impact.

In Indonesia, steam power plants generally use coal as their primary energy source because it is available in large quantities; around 61, 365.86 million tons and reserves of approximately 6, 758.90 million tons [13]. Furthermore, using coal as fuel damages the environment. The negative impact on the environment results both from the mining and from its combustion. However, Indonesia has a huge potential source of renewable biomass energy in the form of agricultural waste. The biomass potential in Indonesia is around 146.7 million tons/year, which is equivalent to 470 GJ/year. Moreover, the largest biomass energy potential derives from rice residues, which is around 150 GJ/year [14]. In 2013, total potential of the CC obtained about 23, 020, 431 tons, equivalent to 14, 426, 142 tons of coal. This potential will generate electrical energy about 21,641 GWh and electric power of about 2, 472 MW. The data shows there are 12 provinces that have the potential of CC which generates electrical power above 10 MW. While the others 21 provinces only have electrical power capacity which is less than 10 MW [15].

Based on these problems, a study was carried out to obtain an overview of the availability of energy potential of MSW and CC as fuel at power plants in several cities in Indonesia. The potential of available CC and PB could be utilized as a source of energy for power plants to overcome shortage of electrical energy without using oil and coal. The utilization of MSW and CC as fuel has been expected to be the solution for problems pertaining to MSW and energy electricity shortage, as well as an alternative substitute for coal in Indonesia. Hence, in addressing the problems related to electrical energy shortages and environmental pollution in Indonesia, an alternative course of action is to exploit the potential of MSW and CC as fuel for power plant. PB has almost the same CV of oil and greater calorific value compared to coal and wood. However, the limited supply of plastic waste becomes a problem as it is insufficient when used as fuel in the power plant. The purpose of this study is to obtain a characteristic of co-oxidative (co-combustion) between CC and PB on the composition ratio of the mixture by wt samples: (90% : 10%), (70% : 30%), and (50% : 50%) as the basis for the application as fuel in the power plant, as well as its contribution in addressing environmental problems and shortage of electricity.

2. MATERIALS AND METHOD

2.1 Preparation process of test material

All samples were sun dried and then cut using cutter. The samples were again ground to obtain a particle size of 0.150 mm. To obtain a homogeneous particle size of 0.15 mm, a sieve of mesh size of 0.150 mm was used.

Subsequently, the sample was heated in Universal oven in Geotechnical Laboratory with a temperature of about 105°C for 7 hours for CC samples and 1 hour for PB samples. This method refers to several previous studies [16-19]. The mixing of samples were performed by weighing each material waste with the mass ratio of CC and PB as: (90%: 10%), (70%: 30%), and (50%: 50%) by using a digital balance. Each composition ratio of the mixture is determined about 10 grams. To obtain a uniform and homogeneous mixture was missed and stirred. This mixture was used for the proximate and ultimate analysis as well as the oxidative environment. A small particle size mixture can certainly a homogeneous blend, thereby ensuring the representation from the mixture in the test sample. In testing the CV of the fuel, proximate and ultimate analyses are required as input data in the modeling. Meanwhile, kinetic studies by oxidative environment are necessary to identify the characteristics of the fuel in the heat treatment process.

2.2 Proximate and ultimate analysis and calorific value

Testing proximate and ultimate analysis and CV refers to previous studies [19-27]. The chemical composition of agricultural residues and PSW had been obtained by applying proximate testing and ultimate analysis. Proximate, ultimate, and CV analyses were carried out to determine the quality of fuel for power plants. Proximate analysis of the samples was conducted to determine the value of energy, moisture content, volatile matter, fixed carbon, and ash content in the fuel. The CV was done according to the standard methods, i.e. ASTM D.5865. Whereas, the ultimate analysis was conducted to determine the chemical components of the sample, which contains carbon, hydrogen, nitrogen, sulfur, and oxygen. Proximate and ultimate analysis will be described in detail.

2.3 Characteristics and parameter kinetic of oxidative

The study on oxidative of CC mixture with PB was conducted to obtain the characteristics parameter kinetic of CC and PB. TGA and DTG curves of CC and mixture with PB (CC₉₀, CC₇₀, and CC₅₀) were obtained from results of test on Mettler (TGA/SDTA851) Laboratory, Faculty of Petroleum and Renewable Energy Engineering, UTM. The characteristics of CC and PB show that the TGA and DTG curves were obtained by using sma4Win software with input data from the results of sample testing. The oxidative analyses were carried out at a temperature of about 30 - 800°C with duration of about 0 - 82 minutes, heating rate (HR) of about 10°C/min and mass test of about 5.38 - 5.60 mg. The oxidative environment used air with flow rate of 50 ml/min. The mass loss fraction for every stage of the thermal decomposition is defined in:



$$\alpha = \frac{M_o - M_i}{M_o - M_a} \quad (2.2)$$

Meanwhile, the activation energy (E_a) that occurred was obtained from linear regression of the Arrhenius law. The calculation results of the E_a was obtained by applying the Arrhenius law principles [19, 26, 28-30], as Eq. (2.3 – 2.6).

$$k = A e^{\frac{-E_a}{RT}} \quad (2.3)$$

The equation can be written in logarithmic form:

$$\ln k = \ln A - \left(\frac{E_a}{RT} \right) \ln e, \text{ where } \ln e = 1 \quad (2.4)$$

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \ln A \quad (2.5)$$

Based on previous studies [26, 28], these equations were obtained:

$$\ln k = -\ln \left[\frac{\ln(1-\alpha)}{T^2} \right] \quad \text{and} \quad \ln A = \ln \frac{AR}{\beta E}$$

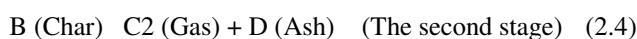
Thus, Eq. (2.5) can be written as:

$$-\ln \left[\frac{\ln(1-\alpha)}{T^2} \right] = \frac{E}{R} \times \frac{1}{T} - \ln \frac{AR}{\beta E} \quad (2.6)$$

where M_0 = the initial mass of solid at the beginning reaction i (mg), M_a = the residue mass the end of reaction i (mg), M_i = the actual mass of reaction i (mg), α = mass loss fraction (mg), E = the heating rate (K/min), k = the reaction rate, A = pre-exponential factor (Arrhenius factor), R = the gas constant (8.314 J/mol.K), E = The activation energy for the reaction (J/mol), and T = the absolute temperature (K). The activation energy (E_a) may then be extracted from a plot of $\ln k$ vs. $1/T$, which should be linear. This plot is called "Arrhenius plot." Besides, Eq. (3.24) can be analogous to equation straight line, which is often symbolized by the linear regression equation: $y = mx + b$. Thus, the $\ln k$ as y-axis, as $1/T$ as x-axis, m = as slope, and b = as the intercept of the line with y-axis.

2.4 Kinetic study of oxidative environment

The study of oxidative environment was conducted to determine the kinetics of the thermal decomposition of biomass in the oxidative environment. Kinetics of thermal decomposition in the process of oxidative environment is more related to the combustion process, so that the results obtained could contribute to the development and the application of co-combustion. In the process of oxidative environment, thermal decomposition of biomass takes place in two stages of reaction kinetic scheme [28], as presented in the following equations:



Equations (2.3) and (2.4) show that the oxidative process has two steps; the first step is the evaporation of the main constituents of biomass and production of charcoal residues at low temperatures. While, the second step includes lignin decomposition and combustion of charcoal produced at an early stage, which has quite a big difference from the presence of oxygen and causes the condition of complexity, such as an increase in the decomposition of the material at low temperature and the promotion of combustion residues. Moreover, it is known that the kinetics of the oxidative decomposition of biomass under inert atmosphere and oxidative is influenced by a variety of equipment, experimental conditions (temperature, pressure, and warming rate), and physical properties of the material.

3. RESULTS AND DISCUSSIONS

3.1 Electrical energy potential of CC

The potential of CC in 2012 was around 5,226,864 tons with an EP_{CC} of around 88,438 TJ. This is equivalent to an EE_{CC} of approximately 24,566 GWh, or equivalent to PP_{CC} of about 2,804 MW [15]. The data shows only the 12 provinces that have the potential CC which generates electrical power above 10 MW, the largest is about 1,824 MW in East Java and Jogyakarta smallest is about 10 MW. While the other 21 provinces only available electrical power capacity is less than 10 MW. Therefore, it can develop a 10 MW power plant with CC, as is presenter in Figure-1.

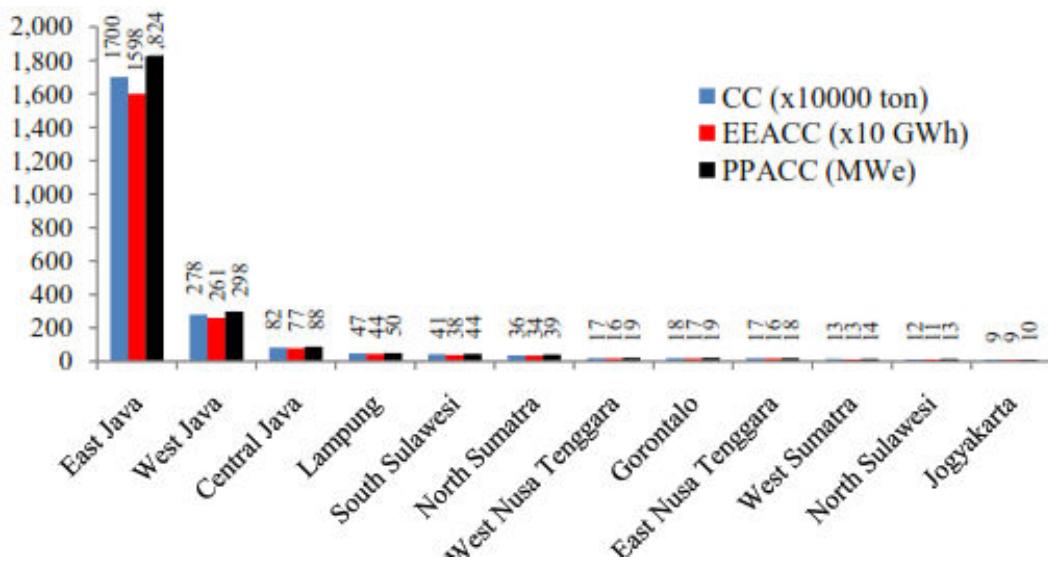


Figure-1. Electrical energy potential and actual electric power of CC is available on 25 provinces in Indonesia.

3.2 Electrical energy potential of MSW and PB as fuel in power plants

The potential energy contained in MSW can be estimated by calculating the amount of MSW generated and CV that is produced by the MSW. Energy potential of MSW (EP_{MSW}) can be calculated based on the calorific value of MSW (CV_{MSW}) about 9,200 kJ/kg [11] or about 9,240 kJ/kg [31-32], and density (ρ_{MSW}) of MSW about

240 kg/m³ [31] and [33]. The potential of MSW generated in 33 cities in Indonesia, only 10 cities that have the potential of electric power above 10 MW, the largest is about 146 MW in Jakarta and Denpasar smallest is about 13 MW, as in presented in Figure-2. The city can develop a 10 MW power plant using MSW, while other cities have to use the system of co-combustion with agriculture residue that is available in every province.

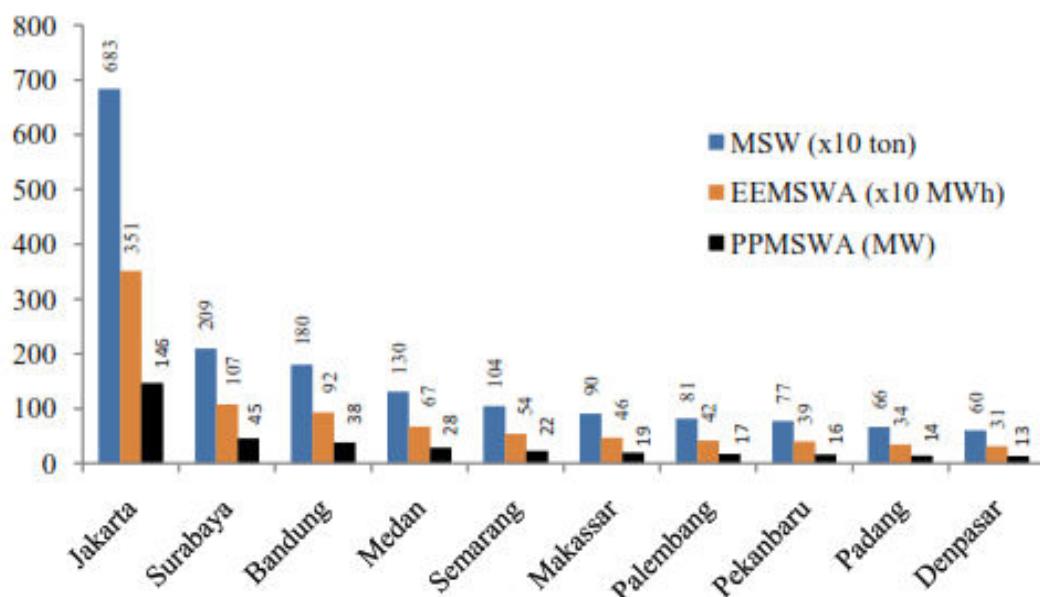


Figure-2. Electrical energy potential and actual electric power of MSW is available on 25 provinces in Indonesia.

The potential energy of PB can be used to substitute the use of coal at the power plant with the principles of co-combustion with coal for improving power plant capital costs [34]. Plastic waste can also be used as fuel supplement to save the use of coal in power plants [35]. The description suggests that the PSW has

energy potential that can be developed as a fuel for co-combustion or mono-combustion at power plants. Potential of PB in Indonesia is still very small in the whole provinces; Jakarta only has about 25 MW of electrical power that can produce approximately 10 MW or greater than 10 MW, while the potential in other provinces is very



smaller than 10 MW. This suggests that the potential merger may increase the amount of the availability of power plants in each province in Indonesia. In developing a 10 MW power plant in each province, the incorporation of fuel necessary (co-combustion) between CC and PB to meet the availability of fuel are required.

3.3 Proximate and ultimate analysis of CC and PB

Test result data on CV, proximate and ultimate analysis of CC on various composition of the mixture with PB, namely 100% of CC (CC_{100}), 90% CC + 10% PB (CC_{90}), 70% CC + 30% PB (CC_{70}), 50% CC+ 50% PB (CC_{50}), and 100% PB (PB_{100}), is presented in Table-1. It shows the addition of PB in CC is increase the CV, VM, carbon content (C), and the hydrogen content (H) which depends on the percentage of the addition of PB in CC. These case shows that the CV is directly proportional

(positive correlation) with C content, H content, and VM of the fuel. In contrast, the percentage of FC, MC, Oxygen (O), Nitrogen (N), and ash is decreased with the addition of a greater percentage of PB. It was found that the content of the element is inversely proportional (negative correlation) with a CV of the fuel. One of the physical properties of the fuel that needs attention is the MC of the fuel. The MC affects the characteristics of the fuel, such as CV and ash produced by the combustion process. The MC is directly proportional (positive correlation) with ash and inversely proportional to the CV of produced. In the combustion process is expected to result in a maximum CV and ash content is expected to be smaller. This shows that the addition of PB in the fuel improve fuel quality, which increases the energy content and lower moisture content and ash content.

Table-1. Test result on CV, proximate and ultimate analysis CC and PB.

No.	Parameter	CC_{100}	CC_{90}	CC_{70}	CC_{50}	PB
1	Calorific value (MJ/kg)	16.92	20.09	25.53	30.22	41.21
2	Proximate Analysis					
	Fixed Carbon (%)	18.18	15.94	12.58	8.64	0.72
	Volatile matter (%)	72.62	73.43	75.87	79.20	89.04
	Moisture content (%)	7.07	7.45	6.13	4.37	0.22
	Ash (%)	2.13	3.18	5.42	7.79	10.02
	Total (%)	100	100	100	100	100
3	Ultimate Analysis					
	C (%)	44.07	45.02	48.20	51.01	67.49
	H (%)	6.33	6.38	6.64	7.41	10.25
	O (%)	46.9	45.05	39.37	33.47	11.92
	N (%)	0.55	0.44	0.32	0.27	0.26
	S (%)	0.02	0.03	0.05	0.05	0.06
	Ash (%)	2.13	3.08	5.42	7.79	10.02
	Total (%)	100	100	100	100	100

The result of study show the addition of PB in CC improve CV, VM, C, and H of the fuel. The higher content of PB in the fuel, the higher the CV, VM, C, and H of the fuel. In contrast, the content of the FC, MC, O, N, and ash decreased. This shows that the addition of PB in the fuel improve fuel quality, which increases the energy content and decrease the MC and AC. Additionally, the addition of PB decrease the production of N, which means it can reduce the production of NOx in the air.

3.4 Oxidative environment of CC_{100} , CC_{90} , CC_{70} , and CC_{50}

The oxidative environment testing conducted to study the characteristics of fuel when receiving the heat treatment with temperature and time are varied. The important characteristics are known as input data for modeling combustion in grate bed furnace. The process of

oxidative environment, thermal decomposition of biomass takes place in two stages of reaction kinetic scheme [28], as presented by the following equation:



The oxidative environment testing performed to study the characteristics of fuels when it receives heat treatment at the temperature and time were varied. This important characteristic is obtained as input data for the combustion model in the bed furnace. The oxidative environment testing was conducted by using a Mettler Toledo TGA/SDTA851. Sample testing of CC_{100} , CC_{90} , CC_{70} , CC_{50} , and PB_{100} was conducted with mass about 5.36 - 5.95 mg, temperatures range about 30 - 800°C, time



range about 0 - 82 minutes, HR about 10°C , and flow rate of air about 50 ml/min. Thermal decomposition (TD) of biomass begins at $200 - 300^{\circ}\text{C}$, and CO, CO_2 , H_2 and H_2O are vaporized as gas. TD is a heat generating reaction which is a characteristic phenomenon of biomass ($\text{C}_n\text{H}_m\text{O}_p$). The main chemical components of biomass are cellulose, hemicelluloses, and lignins are decomposed as the temperature rises. During the combustion, the moisture evaporation occurs in the temperature of $50 - 100^{\circ}\text{C}$. The hemicelluloses decomposition in $200 - 260^{\circ}\text{C}$, followed by cellulose in $240 - 340^{\circ}\text{C}$ and lignin in $280 - 500^{\circ}\text{C}$ [36]. At the oxidative environment, the TD process is complete before temperature of 500°C (about 480°C), as presented in Figure-3 and Table-2.

The oxidative environment test of CC_{100} , CC_{90} , CC_{70} , and CC_{50} conducted with a mass of about 5.42 mg, temperatures range from $30 - 800^{\circ}\text{C}$, time range of 0 - 82 min, HR of $10^{\circ}\text{C}/\text{min}$, and the flow rate of air about 50 ml/min. By using the sma4Win software obtained TGA and TDG curves. The result of oxidative environment process for CC_{100} , the dehydration process (DP) occurs at the temperature of about $50 - 100^{\circ}\text{C}$ with mass loss of about 5.68% (0.31 mg). While the TD process of CC_{100} occurs in 2 stages i.e. the first stage of TD occurs at temperature range of $230 - 340^{\circ}\text{C}$ with mass loss of about 56.42% (3.06 mg). At the second stage, TD occurs in the temperature range of $390 - 450^{\circ}\text{C}$ with mass loss of about 28.30% (1.53 mg). Thus, total mass loss of about 90.4% (4.90 mg) and the remaining approximately 9.60 % of ash. Based on linear regression of the Arrhenius equation, Ea of CC_{100} at the first stage (TD 1) was obtained Ea_1 about 59.75 kJ/mol from linear regression equation: $y_1 = 7187x + 0.862$, $R^2 = 0.949$, occurs at temperature from $230 - 340^{\circ}\text{C}$. The same principle, the TD 2 at the second stage obtained Ea of about 39.35 kJ/mol based on the equation: $y_2 = 4733x + 5.361$, $R^2 = 0.958$, $\text{Ea} = 39.35 \text{ kJ/mol}$ with $T_2 = 390 - 450^{\circ}\text{C}$ with time duration from 34 - 45 minutes. In total, Ea of CC_{100} obtained approximately 99.1 kJ/mol.

The oxidative environment test of CC_{90} , the DP occurs at the temperature of about $50 - 100^{\circ}\text{C}$ with mass loss of about 2.88% (0.16 mg). While the TD process of CC_{90} in 2 stages i.e. the first stage of TD occurs at temperature range of $240 - 360^{\circ}\text{C}$ with mass loss of about 50.09% (2.68 mg). At the second stage, TD occurs in the temperature range of $380 - 490^{\circ}\text{C}$ with mass loss of about 38.261% (1.783 mg). Thus, total mass loss of about 91.23% (4.62 mg) and the remaining approximately 8.77% of ash. Based on linear regression of the Arrhenius equation, Ea of CC_{90} at the first stage (TD 1) was obtained of about $\text{Ea}_1 = 61.64 \text{ kJ/mol}$ from linear regression equation: $y_1 = 7414x + 0.959$, $R^2 = 0.920$, this occurs at temperature from $240 - 360^{\circ}\text{C}$. The same method, the TD 2 at the second stage obtained Ea_2 of about 47.54 kJ/mol

based on the equation: $y_2 = 5718x + 4.324$, $R^2 = 0.939$. This occurs at temperature from $380 - 490^{\circ}\text{C}$ with time duration from 34 - 45 minutes. In total, Ea of CC_{90} obtained approximately 109.18 kJ/mol, is greater than Ea of CC_{100} . This shows with addition PB of about 10% in CC_{90} , improve the Ea of the fuels.

The oxidative environment test of CC_{70} , the DP occurs at the temperature of about $50 - 100^{\circ}\text{C}$ with mass loss of about 3.76% (0.255 mg). While the TD of CC_{70} occurs in 2 stages i.e. the first stage of TD occurs at temperature range of $240 - 370^{\circ}\text{C}$ with mass loss of about 48.07% (2.63 mg). At the second stage, TD occurs in the temperature range from $390 - 460^{\circ}\text{C}$ with mass loss of about 34.61% (1.89 mg). Thus, total mass loss of about 86.437% (4.729 mg) and the remaining approximately 13.564% % of ash. Based on linear regression of the Arrhenius equation, Ea of CC_{70} at the first stage (TD 1) was obtained of about $\text{Ea}_1 = 52.89 \text{ kJ/mol}$ from linear regression equation: $y_1 = 6362x + 2.810$, $R^2 = 0.923$. This occurs at temperature from $240 - 370^{\circ}\text{C}$, during duration from 21 - 35 minutes. The same principle, the TD 2 at the second stage obtained Ea_2 of about 59.88 kJ/mol based on the equation: $y_2 = 7207x + 2.221$, $R^2 = 0.927$. This occurs at temperature from $390 - 460^{\circ}\text{C}$ with time duration from 34-45 minutes. In total, Ea of CC_{70} obtained approximately 112.77 kJ/mol. This shows with addition PB of about 30% in CC_{70} , improve the Ea of the fuels.

The TD process of CC_{50} occurs in 3 stages i.e. the first stage of TD occurs at temperature range of $250 - 370^{\circ}\text{C}$ with mass loss of about 30.53% (1.68 mg). At the second stage, TD occurs in the temperature range of $390 - 470^{\circ}\text{C}$ and duration from 35 - 44 minutes with mass loss of about 49.01% (2.69 mg). At the third stage of about 4.76% (0.26 mg) in the temperature range from $600 - 650^{\circ}\text{C}$. Thus, total mass loss of about 85.02% (4.63 mg) and the remaining approximately 14.98% of ash. Based on linear regression of the Arrhenius equation, Ea of CC_{50} at the first stage (TD 1) was obtained of about $\text{Ea}_1 = 50.96 \text{ kJ/mol}$ from linear regression equation: $y_1 = 6130x + 4.049$, $R^2 = 0.932$, this occurs at temperature from $250 - 370^{\circ}\text{C}$, during duration 22 - 35 minutes. The same principle, the TD 2 at the second stage obtained $\text{Ea}_2 = 28.22 \text{ kJ/mol}$ based on the equation: $y_2 = 3394x + 8.693$, $R^2 = 0.928$. This occurs at temperature from $390 - 470^{\circ}\text{C}$ with time duration from 34 - 45 minutes. The TD 3 at the third stage obtained $\text{Ea}_3 = 42.44 \text{ kJ/mol}$ based on the equation: $y_3 = 5105x + 6.790$, $R^2 = 0.903$. This occurs at temperature from $600 - 650^{\circ}\text{C}$ with time duration from 58 - 65 minutes. In total, Ea of CC_{50} obtained approximately 121.62 kJ/mol, is greater than Ea of CC. This shows with addition PB of about 50% in CC_{50} , improve the Ea of the fuels.

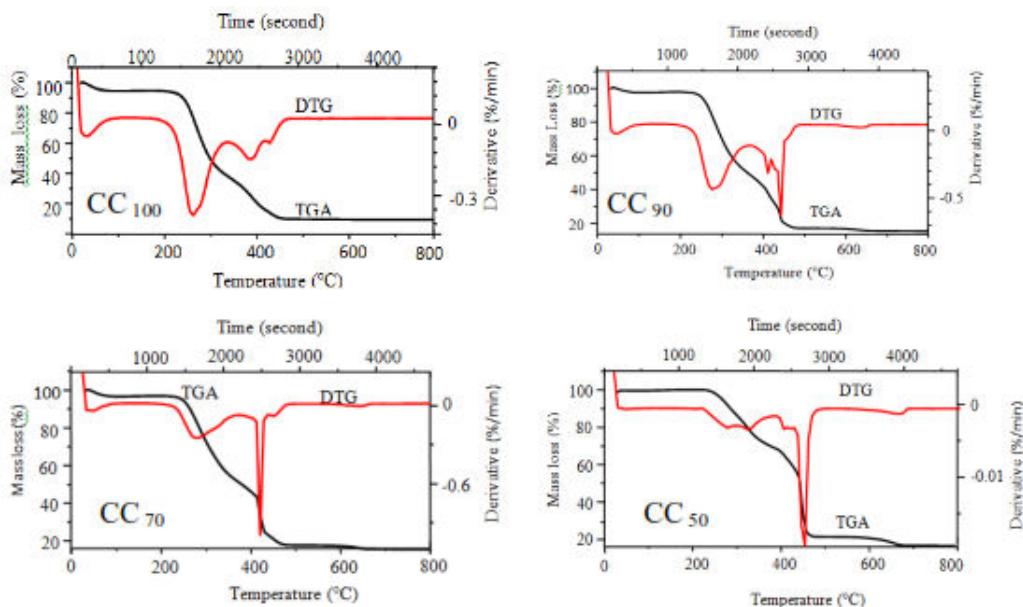


Figure-3. TGA and DTG Curves of CC₁₀₀, CC₉₀, CC₇₀, and CC₅₀ for oxidative environment with HR of 10°C/min and the flow rate of air of about 50 ml/min.

Table-2. Linear regression of Arrhenius equation for oxidative environment.

Materials	DT (°C)	Linear regression of Arrhenius equation	(R ²)	Activation energy Ea (kJ/mol)			Total
				Ea ₁	Ea ₂	Ea ₃	
CC ₁₀₀	230 - 340	y ₁ = 7187x + 0.862 y ₂ = 4733x + 5.361	0.949	59.75	-	-	-
	390 - 450		0.958	-	39.35	-	99.1
CC ₉₀	240 - 360	y ₁ = 7414x + 0.959	0.920	61.64	-	-	-
	380 - 490	y ₂ = 5718x + 4.324	0.939	-	47.54	-	109.18
CC ₇₀	240 - 370	y ₁ = 6362x + 2.810	0.923	52.89	-	-	-
	390 - 460	y ₂ = 7207x + 2.221	0.927	-	59.88	-	112.77
CC ₅₀	250 - 370	y ₁ = 6130x + 4.049	0.932	50.96	-	-	-
	390 - 470	y ₂ = 3394x + 8.693	0.928	-	28.22	-	-
PB ₁₀₀	600 - 650	y ₃ = 5105x + 6.790	0.903	-	-	42.44	121.62
	290 - 430	y ₁ = 11010x - 2.033	0.956	91.54	-	-	-
	430 - 470	y ₂ = 15670x - 8.520 y ₃ = 4681x + 7.423	0.932	-	130.28	38.92	260.74
	600 - 680		0.920	-	-	-	-

The data showed that the addition of PB in biomass increase the activation energy (Ea) of fuel. The higher of PB in the CC, the Ea produced will be even greater. But required a longer time and higher temperature to perform decomposition perfectly. The TD process of combustion occurs in 3 stages the temperature range. Fuel decomposition process including PB will end completely at the 700 - 800°C. In the table obtained the value of correlation coefficient R² in the range of 0.90 - 0.979, which means that the relationship between the variables in the equation is very strong and the high level of confidence in the linear regression equation and Ea. Ea generated at each fuel mixture in the oxidative process.

3.5 Kinetic study of CC₁₀₀, CC₉₀, CC₇₀, and CC₅₀

Table-3 shows the kinetic parameters study of CC₁₀₀, CC₉₀, CC₇₀, CC₅₀, PB₁₀₀, the process of dehydration in all the samples occurs in the same temperature range

from 50 - 100°C. While the TD process occurs in the same temperature range from 240 - 360°C, 370 - 480°C, and 600 - 670°C, except PB occurs at the temperature range from 300 - 440°C, 450 - 480°C, and 600 - 670°C. The greater percentage of PB in the fuel mixture, the smaller the resulting ash residue. The ash residue produced in the process of oxidative environment of the fuel mixture variations of CC and PB. The dehydration process (DP) occurs at the temperatures around 50 - 100°C with mass loss occurs around 2 - 7% (depending on the water content of the fuel). In the process of oxidative environment, TD generally occurred in two stages, except PB and fuel containing 50% PB takes place in three stages of the TD. This happens because the fuel that contains a lot of PB, the TD process cannot be perfect in a short time and requires a high temperature around 600 - 670°C to perform the decomposition process perfectly. In the process of oxidative environment, CC and mixture up to 30% PB,



perfect TD occurs at temperatures around 480 - 500°C. While PB₁₀₀ and PB₅₀, the perfect decomposition at temperatures around 600 - 670°C. At the temperature conditions, fuel generate the maximum energy, meaning that all potential chemical energy in the fuel optimally

transformed into thermal energy. This illustrates that the use as fuel in furnaces, combustion temperature minimum required 500 - 700°C (773 - 973 K) to produce energy optimally.

Table-3. Parameter of kinetic study for oxidative environment of CC, and PB.

Materials	Mass test (mg)	DP		TD1		TD 2		TD 3		Ash residues (%)
		ML (%)	T (°C)	ML (%)	T (°C)	ML (%)	T (°C)	ML (%)	T (°C)	
CC ₁₀₀	5.4	5.7	50 - 100	56.5	230-350	28.3	360-470	-	-	9.5
CC ₉₀	5.4	2.9	50 - 100	50.1	240-370	38.3	380-490	-	-	8.7
CC ₇₀	5.4	3.8	50 - 100	48.1	240-370	34.6	380-480	-	-	13.5
CC ₅₀	5.5	-	-	30.5	240-380	49.0	390-470	4.8	600-670	15.7
PB ₁₀₀	5.5	-	-	48.5	300-440	37.7	450-480	7.7	600-670	6.1

4. CONCLUSIONS

Corn Cob (CC) and plastic bag (PB) have excellent potential prospects as future fuel in Indonesia. This potential is increased annually on an average of 1.5 - 2% due to increasing corn production and population growth. The potential of CC only 11 provinces can generate a power capacity of about 13 MW to 1,824 MW. The potential of PB only Jakarta which has the potential approximately 24.6 MW, while the other provinces are smaller than 10 MW. In order to overcome the shortage of fuel supplies needed for the power plant in each province, the most appropriate solution is the combustion of CC and PB mixture.

The results of the proximate and ultimate analysis showed that the addition of PB in CC increased CV, VM, C, and H content. In contrast, the percentage of FX, MC, O, N, and ash, decreased. The addition of PB can improve the physical and chemical properties of CC, particularly an increase in CV, and a decrease in MC and ash content. This means that the addition of PB in CC causes a change in the physical and chemical characteristics of the fuel. In the process of oxidation environment of CC, TD process, occurs in two stages, namely when the temperature range is from 230 - 380°C and 350 - 480°C. While, CC and PB mixture about 50% occurred in three stages, namely, from 240 - 380°C, 380 - 480°C, and 600 - 670°C. In particularly PB, TD process occurred at 300 - 400°C and 600 - 670°C. The addition of PB in CC caused the stages in the TD process to increase, the activation energy and the CV were also increased, but the carbon residue and ash residue decreased.

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