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Contributed Paper

Co-pyrolysis of Rice Straw with High Density Polyethylene Bag

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ABSTRACT

A co-pyrolysis study was conducted to examine the characteristics of rice straw (RS) with high density polyethylene (HDPE) bag or plastic bag waste (PB) as the energy source. The determination of RS characteristics with PB mixtures of about 10%, 30%, and 50% was conducted by a thermogravimetric analysis at the temperatures of 30-800°C, time range of 0-82 min, heating rate of 10°C/min, and the flow rate of nitrogen of 50 ml/min. Kinetic studies were performed using the Arrhenius law to determine the activation energy. The dehydration process occurs at the temperature range of 40-110°C. Thermal decomposition occurs at the temperature range of 200-340°C, 400-500°C, and 580-670°C. The greater the percentage of PB in RS, the higher the value of E_a is produced. It is concluded that RS co-pyrolysis with PB had met the characteristic requirement as an energy source. The results can be implemented in gasification and combustion to overcome electricity shortage and MSW in Indonesia.

Keywords: plastic bag, rice straw, kinetic study, co-pyrolysis, HDPE

1. INTRODUCTION

Indonesia's dependence on fossil fuels is still very high, almost reaching 95%. In 2011, oil is still a source of energy with the largest share, at 49.5% of the total energy of about 1,176 billion barrels of oil equivalent. Furthermore, coal and gas were in the proportion of 26% and 20.4%, respectively. This condition needs serious attention because fossil energy reserves are dwindling from year to year. Indonesia's oil potential is

feared to be exhausted in about 23 years, while natural gas and coal are estimated to be exhausted in 55 and 83 years from the year 2011, respectively. These conditions require optimizing the utilization of new and renewable energy to meet the needs of electrical energy. The availability of electrical energy in Indonesia is still lacking, with the electrification ratio in 2011 at 72.95%, and there are still 27.05% of households that do

not get electricity services, especially in remote areas [1]. The potential for renewable energy resources in Indonesia is very large, including the agricultural energy, which can be used as a source of electrical energy. In 2013, the potential for rice straw (RS) was around 106.31 million tons, with a potential surplus of 5.89 million tons, which is the equivalence to the potential energy of about 325,204 TJ [2]. The potential of RS in Indonesia has an average increase of approximately 2-3.1% per year [3].

Additionally, the potential energy of municipal solid waste (MSW) is quite large and has not been used as a source of energy. In 2010, the potential of plastic solid waste (PSW) from MSW in Indonesia reached 693 tons with the energy potential of 28,752,528 MJ, which is equivalent to 1,065 tons of coal or 593 ton of oil [4]. Plastic bags (PB) made of high density polyethylene (HDPE) have the potential to pollute the environment because it cannot be recycled, so it does not have economic value. However, PB has a great energy potential with a calorific value (CV) of about 41.2 MJ/kg, while the CV of RS is about 13.6 MJ/kg. Based on the CV and the potential for availability from both of the wastes, they were considered in the co-pyrolysis study conducted to determine the feasibility of the application as an alternative fuel by gasification and combustion in the power plant.

The study on pyrolysis of RS as a source of energy has been done many times before [5 - 11], as did the studies on PB [12, 13]. Thermogravimetric analysis is useful to study the kinetic decomposition reaction, mechanism of the thermal decomposition (TD) and combustion of biomass. Some literatures have extensively demonstrated the thermochemical pyrolysis and combustion of biomass to produce energy and chemicals.

Similarly, PB is derived from MSW and the pyrolysis treatment of MSW has been made to provide alternative energy resources and chemical raw materials. The main component of MSW is derived from cellulose or lignin polymer-based materials and inorganic materials. Co-pyrolysis method has received much attention because this method has the potential for reducing the volume of waste, recovering of various chemicals, and replacing fossil fuels [14]. The study of co-pyrolysis is important and it is fundamental to know the characteristics of the thermal treatment, mechanism, and the transformations that occur during the thermo-chemical conversion process. The process of converting biomass into fuel is an early stage before the thermo chemical process for gasification and combustion. Therefore, it is very important to understand the kinetics of pyrolysis for feasibility assessment, design, and application of biomass conversion in the industry as an alternative fuel in the power plant.

A co-pyrolysis study was performed to obtain the characteristic of RS and PB mixtures (10%, 30%, and 50% of PB) to the varying times and temperatures in the heat treatment. The results obtained were included into the feasibility assessment material as an alternative fuel to generate electricity, particularly in Indonesia.

2. MATERIALS AND METHODS

2.1 Materials

The sample materials in this study are RS and PB (HDPE) as the alternative energy source. All samples were sun dried and then, a size reduction of the raw materials was done using a cutter and a grinding mill. The samples were again grounded to obtain a particle size of 0.125 mm. The sieving of the raw materials was done to obtain uniformity in size of about 0.125-0.3 mm

phase and char were the result of pyrolysis residues. The approximate compositions of hemicelluloses, cellulose, and lignin in the RS were 30-35%, 21-31%, and 4-19%, respectively [15]. However, the results of another study reported that NaOH pretreated RS that consisted of cellulose about 58.11%, hemicelluloses 21.68%, and lignin 4.15% [23].

The characterizations of RS and PB were done using thermogravimetric data to investigate the kinetic reactions on the results of TD. Chemical kinetics of pyrolysis and description of transport phenomena can provide useful information for the design and optimization of thermo-chemical systems. As were done in the previous studies [15, 24-27], kinetic parameters were calculated using the Arrhenius law by the equation:

$$k(T) = A e^{k_p \left(\frac{-E}{RT}\right)} \quad (2)$$

$$\frac{d\alpha}{dt} = A e^{-E/RT} (1 - \alpha)^n \quad (3)$$

where A is the pre-exponential or frequency factor, E is the activation energy of the reaction, R is the universal gas constant (8.314 J/mol.K), T is the absolute temperature, n is the order of reaction, t is time, and a is the fraction of the reactants decomposed at time, t (min). The extent of reaction, a, is defined in terms of the mass change in the samples or mass of volatiles produced.

$$\alpha = \frac{M_0 - M_i}{M_0 - M_a} \quad (4)$$

where α is the mass loss fraction (mg), M_0 is the initial mass of the sample at the beginning reaction (mg), M_i is the actual mass of the maple (mg), and M_a is the final mass of the sample (mg). For the constant heating rate (β), the following equation can be expressed:

$$\beta = \frac{d\alpha}{dT} = \frac{d\alpha}{dt} \frac{dt}{dT} \quad (5)$$

The term $d\alpha/dT$ is the non-isothermal reaction rate and substituting Eq.(5) into Eq.(2) will result to as follows:

$$\frac{d\alpha}{dT} = \frac{A}{\beta} e^{-E/RT} (1 - \alpha)^n \quad (6)$$

Integrating Eq. (6), the following equation can be obtained:

$$\frac{1 - (1 - \alpha)^{1-n}}{1 - n} = \frac{A}{\beta} \int_0^T e^{-E/RT} dT \quad (7)$$

Since $\int e^{-E/RT} dT$ has no exact integral, $e^{-E/RT}$ can be expressed as an asymptotic series and its integration by ignoring the higher order terms which gives:

$$\frac{1 - (1 - \alpha)^{1-n}}{1 - n} = \frac{ART^2}{\beta E} \left[1 - \frac{2RT}{\beta E} e^{-E/RT} \right] \quad (7)$$

Expressing Eq. (8) in a logarithmic form will result in the following Eq.(9):

$$\ln \left[\frac{1 - (1 - \alpha)^{1-n}}{T^2(1 - n)} \right] = \ln \left[\frac{AR}{\beta E} \left[1 - \frac{2RT}{E} \right] \right] - \frac{E}{RT} \quad (\text{for } n \neq 1) \quad (9)$$

If assuming that $2RT/E \ll 1$, then Eq. (9) becomes:

$$\ln \left[\frac{1 - (1 - \alpha)^{1-n}}{T^2(1 - n)} \right] = \ln \left[\frac{AR}{\beta E} \right] - \frac{E}{RT} \quad (\text{for } n \neq 1) \quad (10)$$

In order to simplify the calculations, the order of the reaction, n, is assumed to be unity, and hence, Eq. (10) can be presented as follows:

$$\ln \left[-\frac{\ln(1 - \alpha)}{T^2} \right] = \ln \left[\frac{AR}{\beta E} \right] - \frac{E}{RT} \quad (11)$$

The Eq. (11) will result in a straight line with the slope $-E/R$ and an intercept of $\ln [AR/\beta E]$. This was done by plotting the graph between the following:

$$\ln \left[-\frac{\ln(1 - \alpha)}{T^2} \right] \text{ versus } \left[\frac{1}{T} \right] \quad (\text{for } n \neq 1) \quad (12)$$

The values of α and T will be obtained from the thermogravimetric analysis. The criteria used for the acceptable values of E and A were the final value of n that should yield the values of E_a and the linear correlation coefficient (R^2) of the most appropriate (> 0.90). Eq. 11 can be analogous to the equation of the straight line, which is often symbolized by the linear regression equation: $y = mx + b$. Thus, the $-\ln\left[\frac{\ln(1-\alpha)}{1-\alpha}\right]$ is the y -axis, $\frac{1}{T}$ is the x -axis, $m = \frac{E_a}{R}$ is the slope, and $b = \ln\frac{AR}{BE}$ is intercept of the line with y -axis. The E_a at each TD (mass loss) was obtained by using Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1 Characterization of Fuels

The characteristic parameters of the fuel that were obtained from the proximate and ultimate analysis results are presented in Table 1. The CV of RS was 13.56 MJ/kg, while the addition of PB to 10%, 30%, and 50% in RS increased the CV of R_9P_1 ,

R_7P_3 , and R_5P_5 to 19.82 MJ/kg, 24.68 MJ/kg, and 29.64 MJ/kg, respectively. Similarly, the values of VM, C, and H were increased by the amount of percentages of PB in the RS. This data showed that the CV was directly proportional (positive correlation) with the VM, C, and H of the fuel. In contrast, the percentages of FC, MC, O, N, S, and ash were decreased with the addition of a greater percentage of PB. It was found that the CV was inversely proportional (negative correlation) with the FC, MC, O, N, and ash of the fuel. One of the physical properties of the fuel that needed attention was the MC. It affected the characteristics of the fuel, such as CV and ash produced by the combustion process. The MC was directly proportional (positive correlation) with ash. The combustion process was expected to produce a maximum CV and the ash content was expected to be at minimum. A higher CV will generate more energy and a larger power.

Table 1. Test result on CV, proximate and ultimate analysis of RS and PB.

No.	Parameters	Unit	RS	R_9P_1	R_7P_3	R_5P_5	PB
1	CV	(MJ/kg)	13.56	19.82	24.68	29.64	41.21
2	Proximate Analysis						
	FC	(%)	14.87	13.90	10.58	7.26	0.72
	VM	(%)	55.07	58.88	65.93	72.76	89.04
	MC	(%)	11.55	9.93	7.43	5.46	0.22
	Ash	(%)	18.51	17.29	16.06	14.52	10.02
3	Ultimate Analysis						
	C	(%)	39.52	43.22	47.86	53.14	67.49
	H	(%)	5.46	5.81	6.71	7.67	10.25
	O	(%)	35.67	33.04	28.82	24.26	11.92
	N	(%)	0.74	0.66	0.47	0.34	0.26
	S	(%)	0.1	0.09	0.08	0.08	0.06
	Ash	(%)	18.51	17.18	16.06	14.51	10.02

Table 1 shows that the addition of PB in RS can improve the quality of fuel, especially increasing the CV, VM, C, and H. Additionally, it will also decrease the MC, O, S, N, and ash. The percentage content of C and H increased, especially in the composition of 50% (sample of R_5P_5), which meant a greater contribution to the energy released. However, the percentage of O in the fuel decreased, which meant enlarging the content of C and H as well as increasing the heating value (HHV and LHV) of fuel (based on the Dulong formula). In addition, greater combustion air was required in the process of fuel combustion. The O content was also directly proportional to the ash content of the fuel, as shown in the samples RS, R_9P_1 , R_7P_3 , R_5P_5 , and PB. The higher the content of VM in the fuel, the easier it would be to burn the light up and improve the qualities of the combustion and gasification processes. The value of N will reduce the NO_x emissions in the air, while a low S can reduce or minimize pollution and corrosion. The high value of VM, ash, and the low amount of MC were the important characteristics required in the process of fuel combustion. A high MC will aggravate the chemical properties of the fuel due to the complicated process of the fuel ignition. A high ash content can affect the rate of combustion, aggravating the combustion process, result in a reduction of energy, poor combustion, slag formation, and increase the cost of handling, processing, and disposal [15].

3.2 Thermal Decomposition Characteristics

The pyrolysis processes of RS and PB were conducted as a comparison between the co-pyrolysis of R_9P_1 , R_7P_3 , and R_5P_5 . Based on the results of thermogravimetric analysis as presented in Table 2, the dehydration process (DP) of RS occurred at

the temperature range of 40-110°C and the TD process occurred in one stage at the temperature range of 200-500°C. This value had similarities with the results of previous studies with the same heating rates [4, 28]. This was consistent with the TD process of cellulose, which consisted of hemicelluloses decomposition (200-260°C), followed by hemicelluloses decomposition (200-260°C), followed by cellulose decomposition (240-340°C) and lignin decomposition (280-500°C). When the temperature reached to about 500-600°C, the pyrolysis reaction was completed [22].

Several previous studies [21, 29] reported the pyrolysis process of RS with different heating rates. The increase in heating rate on the pyrolysis process affected the position of the TG curve and the maximum level of decomposition, and the location of the peak on the DTG curve which was the main decomposition zone shifted to a higher temperature range. Similarly, the rate of ML increased and the maximum value DTG curve also shifted to higher temperatures. Furthermore, the wheat straw with the different heating rate [30] showed at the higher heating rate, the decomposition process shifted to a higher temperature, as shown in the TD process that occurred at temperatures ranging 200-500°C, 200-550°C, and 200-600°C with the heating rates of 10 K/min, 15 K/min, and 20 K/min, respectively.

Meanwhile, the TD of PB occurred at the temperature range of 400-450°C, and 620-710°C, without performing the DP because PB is one of the non-polar materials. The co-pyrolysis process of R_9P_1 , R_7P_3 , and R_5P_5 , TD process occurred in four zones, with the temperature ranges from 40-100°C, 200-340°C, 400-450°C, and 690-680°C. Based on the results of thermogravimetric analysis as presented in Table 2, by using

the *Sma4Win* software, the TGA and DTG curves of RS, R₉P₁, R₇P₃, R₅P₅, and PB were obtained, as shown in Figure 1.

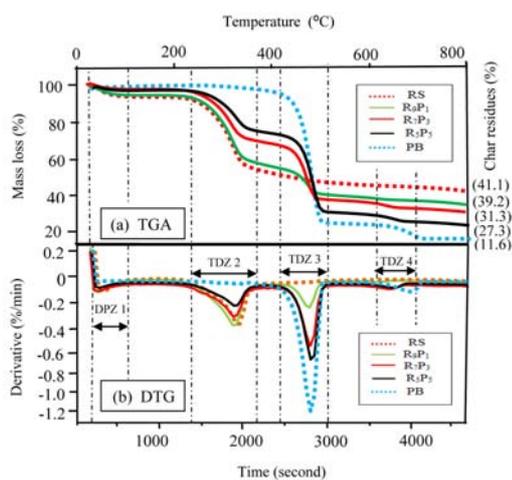


Figure 1. TGA (a) and DTG (b) curves of RS, R₉P₁, R₇P₃, R₅P₅, and PB at heating rate of 10pC/min, temperatures decomposition of 30-800°C, and N flow rate of 50 ml/min.

The process of TD and the resulting char residue on each sample (RS, R₉P₁, R₇P₃, R₅P₅, and PB) are shown in the TGA curve (Figure 1a). The values of TD in each zone are presented in the DTG curve (Figure 1b). The TD process occurred in four zones, where a greater TD process occurred at the third zone and produced a large E_a . The process of decomposition of any material is presented in detail in Table 2. It shows the pyrolysis process of RS where the DP in the first zone (DPZ 1) that occurred in the temperature range of 40-110°C with a mass loss (ML) of about 6.4%. In this case, the MC of RS was removed to approximately 6.4% with the heating process at the temperature range of 40-110°C. The TD process in the second zone (TDZ 2) occurred in the temperature range of 200-340°C with the ML at 52.5%. Thus, the TD process of RS in the pyrolysis remained approximately 42.1% as liquid and char. The co-pyrolysis

process of R₉P₁, R₇P₃, and R₅P₅, and TDZ 2 occurred in the temperature range of 200-340°C with the ML at about 36.4%, 28.9%, and 22.6%, respectively. In this condition, the RS component in the fuel turned into TD perfectly, while the PB components started to go into TD in the third zone (TDZ 3) at the temperature range of 400-500°C with the ML at about 15.1%, 30.7%, 41.6%, and 79.7% for R₉P₁, R₇P₃, R₅P₅ and PB, respectively. In this case, it appeared that the greater the content of PB in the fuel, the greater the ML. Similarly, the TD process in the fourth zone (TDZ 4) was done for R₉P₁, R₇P₃, R₅P₅ and PB in the temperature ranges of 590-660°C, 590-670°C, 600-680°C, and 620-710°C, with the ML at 4.4%, 6.1%, 6.4%, 8.8%, respectively. TDZ 4 showed that the greater the content of PB in the fuel, the greater the ML. In total, the co-pyrolysis of R₉P₁, R₇P₃, R₅P₅, and ML occurred at approximately 60.9%, 68.7%, 72.7%, 88.4%, so the char residues generated were approximately 39.1%, 31.3%, 27.3%, respectively. In this case, it appeared that there was a smaller ash content with the increasing percentage of PB in the fuel. These characteristics indicated the use of R₉P₁, R₇P₃, and R₅P₅ as fuel, with the minimum required combustion temperature of about 590-710°C. The addition of PB had a significant influence on the characteristics of R₉P₁, R₇P₃, and R₅P₅, which was different from the characteristics of RS.

3.3 Kinetic Parameters Analysis

Based on the data in Table 2 and by using Microsoft Excel the linear regression of the Arrhenius equation, R₉P₁ was obtained at every stage of TD. TDZ 2 occurred at the temperatures of about 200-340°C. In this condition, $E_{a1} = 49.82$ kJ/mol was obtained, based on the linear regression equation: $y_1 = 5992x + 3.262$, $R^2 = 0.986$. The linear

regression curve of R_9P_1 is shown in (Figure 1a). The same method, TDZ 3 obtained $E_{a_2} = 40.71$ kJ/mol based on the equation: $y_2 = 4897x + 6.087$, $R^2 = 0.924$ that occurred at the temperature range of 673-773 K (400-500°C). The fourth stage obtained $E_{a_3} = 47.72$ kJ/mol based on the equation: $y_3 = 574x + 13.12$, $R^2 = 0.943$ at the temperature from 863-933 K (590-660°C). In total, the E_a of R_9P_1 that was obtained was about 95.3 kJ/mol, which was greater than the E_a of RS. Meanwhile, the sample of R_7P_3 at the TDZ 2 obtained

$E_{a_1} = 43.51$ kJ/mol based on the linear regression equation: $y_1 = 5233x + 3.844$, $R^2 = 0.990$ (Figure 2b). With the same method, TDZ 3 obtained $E_{a_2} = 77.35$ kJ/mol based on the equation: $y_2 = 9303x - 0.407$, $R^2 = 0.907$. This occurred at the temperature range of 673-773 K (400-500°C). In the fourth stage, the equation: $y_3 = 1566x + 10.08$, $R^2 = 0.925$ obtained $E_{a_3} = 13.01$ kJ/mol at the temperature range of 863-943 K (590-660°C). In total, the E_a of R_7P_3 obtained was about 133.87 kJ/mol, which was greater than the E_a of RS and the E_a of R_9P_1 .

Table 2. The thermogravimetric analyzer results of the co-pyrolysis process.

Fuel	MS(g)	DPZ 1		TDZ 2		TDZ 3		TDZ 4		Char residue (%)
		ML(%)	T(°C)	ML(%)	T(°C)	ML(%)	T(°C)	ML(%)	T(°C)	
RS	5.6	6.4	40-110	52.5	200-500	-	-	-	-	41.1
R_9P_1	5.7	4.9	40-110	36.4	200-340	15.1	400-500	4.4	590-660	39.1
R_7P_3	5.5	3.1	40-110	28.9	200-340	30.7	400-500	6.1	590-670	31.3
R_5P_5	5.5	2.1	40-110	22.6	200-340	41.6	400-500	6.4	600-680	27.3
PB	5.6	-	-	-	-	79.7	400-500	8.8	620-710	11.6

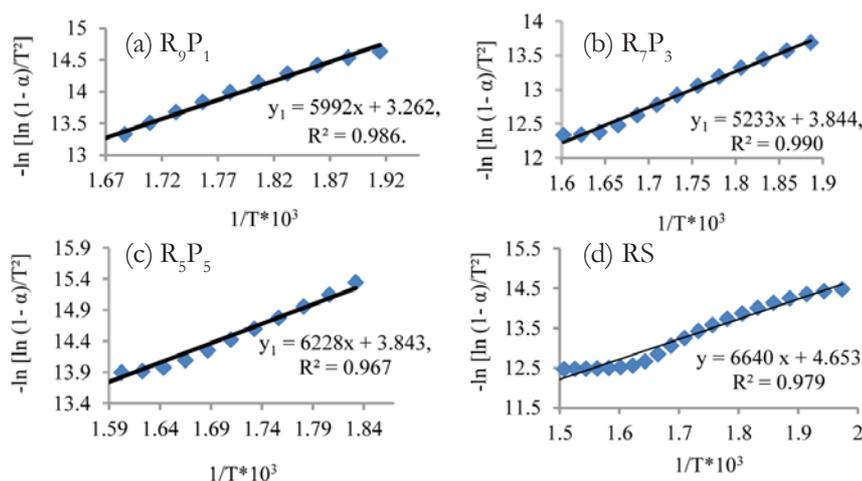


Figure 2. The linear regression curve of $-\ln [\ln (1-\alpha)/T^2]$ vs. $1/T*10^3$ for R_9P_1 , R_7P_3 , R_5P_5 , RS.

Similarly, in the sample of R_5P_5 , TDZ 2 that occurred at the temperature of about 200-340°C, obtained $E_{a1} = 51.78$ kJ/mol, based on the linear regression equation: $y_1 = 6228x + 3.843$, $R^2 = 0.967$. The linear regression curve of $-\ln [\ln (1-\alpha)/T^2]$ vs. $1/T \cdot 10^3$ of R_5P_5 is shown in (Figure 2c). Using the same method, TDZ 3 obtained $E_{a2} = 111.33$ kJ/mol based on the equation: $y_2 = 13390x - 4.768$, $R^2 = 0.925$ at temperature range of 673-773 K (400-500°C). The fourth stage obtained $E_{a3} = 21.13$ kJ/mol, based on the equation: $y_3 = 2542x + 9.741$, $R^2 = 0.951$ at the temperature range of 873-953 K (600-680°C). In total, the Ea of R_5P_5 obtained was about 184.24 kJ/mol, which was greater than the Ea of RS, R_9P_1 , and R_7P_3 . This showed that the addition PB in R_9P_1 , R_7P_7 , and R_5P_5 , improved the Ea of the fuels.

As a comparison, the co-pyrolysis of R_9P_1 , R_7P_7 , and R_5P_5 , Ea of RS and PB were determined at each TD. The TD at RS

pyrolysis process occurred in the temperature range of 200-500°C, thus obtaining $E_a = 55.21$ kJ/mol. K based on Arrhenius Law by using the linear regression equation: $y = 6640x + 4.653$, $R^2 = 0.979$ (Figure 2d). This value was almost equal to the previous study [28] with a heating rate of 10°C/min, where the TD occurred in the temperature range of 200-500°C, thus obtaining $E_a = 59.93$ kJ/mol. K based on the linear regression equation: $y = 7208.6x - 16.705$, $R^2 = 0.9952$. The TDZ 1 of PB occurred at the temperature of about 400-500°C obtained $E_{a1} = 211.43$ kJ/mol based on the linear regression equation: $y_1 = 25430x - 20.44$, $R^2 = 0.989$ (Figure 2c). The same method, the TDZ 2, obtained $E_{a2} = 44.03$ kJ/mol, based on the equation: $y_2 = 5296x + 6.935$, $R^2 = 0.907$ at temperature range of 883 - 963 K (620 - 710pC). In total, the Ea of PB that was obtained was about 255.46 kJ/mol.

Table 3. Linear regression of Arrhenius function and activation energy for co-pyrolysis.

Materials	Temperature decom-position (C)	Linear regression of Arrhenius equation	(R^2)	Ea (kJ/mol)			
				E_{a1}	E_{a3}	Total	
RS	200 - 500	$y_1 = 6640x + 4.653$	0.98	55.21	-	-	55.21
R_9P_1	200 - 340	$y_1 = 5992x + 3.262$	0.99	49.8	-	-	-
	400 - 500	$y_2 = 4897x + 6.087$	0.93	-	40.7	-	-
	590 - 660	$y_3 = 574x + 13.12$	0.94	-	-	4.8	95.3
R_7P_3	200 - 340	$y_1 = 5233x + 3.844$	0.99	43.5	-	-	-
	400 - 500	$y_2 = 9303x - 0.407$	0.91	-	77.4	-	-
	590 - 660	$y_3 = 1566x + 10.08$	0.93	-	-	13.0	133.9
R_5P_5	200 - 340	$y_1 = 6228x + 3.843$	0.97	51.8	-	-	-
	400 - 500	$y_2 = 13390x - 4.768$	0.93	-	111.3	-	-
	600 - 680	$y_3 = 2542x + 9.741$	0.95	-	-	21.1	184.2
PB	400 - 500	$y_1 = 25430x - 20.44$	0.99	211.4	-	-	-
	620 - 710	$y_2 = 5296x + 6.935$	0.97	-	44.0	-	255.5

Based on the analysis of kinetic studies, the determination of E_a at each TD was conducted based on the linear regression equation. The value of correlation coefficient (R^2) showed the relationship between the variables x and y . The linear regression equation can be used to determine the value of E_a when the value $R^2 > 0.9$ (Table 3). It can be seen that the E_a of PB was greater than the E_a of RS. The E_a increased with the increasing percentage of PB in RS. The results of PB pyrolysis generated an E_a of about 255.5 kJ/mol, which was very large if compared with the E_a of RS, which was about 52 kJ/mol. The greater the addition of PB in the RS, the greater the E_a generated. The addition of PB to approximately 10%, 30%, and 50% in RS can improve the E_a of R_9P_1 , R_7P_3 , and R_5P_5 to approximately 81%, 154%, and 250%, respectively. The co-pyrolysis results showed that the addition of PB can improve the thermal characteristics of the RS to improve the performance, resulting in a large energy and lowering the char residue.

4. CONCLUSIONS

Co-pyrolysis of PB into the RS showed an increase in the thermal characteristics of the fuel samples. The higher percentage addition of PB into the RS on the samples R_9P_1 , R_7P_3 , and R_5P_5 generated the higher the content of calorific value, volatile matter, hydrogen, and carbon of the samples. However, the contents of oxygen, nitrogen, sulfur, moisture, and ash decreased. Similarly, the addition of PB into RS showed an increase of the activation energy of samples and reduced charcoal residue content. Thus, the use of PB as a mixture of RS besides increasing the calorific value and the activation energy was to reduce NO_x and SO_x emissions in the air that caused

environmental pollution. This showed the use of PB as a mixture of RS had the eligibility as a source of energy in the process of gasification and combustion. The expected utilization of this waste could be an alternative fuel to overcome the shortage of electrical energy, reduce the use of coal, and overcome the problem of plastic waste in Indonesia.

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