PAPER • OPEN ACCESS

Pyrolysis characteristic of rice husk with plastic bag as fuel for power generation by using a thermogravimetric analysis

To cite this article: Muhammad Anshar *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **105** 012034

View the article online for updates and enhancements.

Pyrolysis characteristic of rice husk with plastic bag as fuel for power generation by using a thermogravimetric analysis

Muhammad Anshar[1,4], Dahlang Tahir[2], Makhrani[2] and Farid Nasir Ani[3]

[1] Department of Mechanical Engineering, State Polytechnic of Ujung Pandang, Makassar, Indonesia.
[2] Department of Physics, Hasanuddin University, Makassar, Indonesia.
[3] Department of Thermodynamics and Fluid Mechanics, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.

E-mail: M.Anshar60yahoo.com

Abstract. Determination of the characteristics of rice husk (RH) with plastic bag (PB) mixture as a source of energy is carried out in pyrolysis study. Test characteristics of RH with PB mixture is performed by using a thermogravimetric analysis at temperatures from 30 - 800$^\mathbf{o}$C, heating rate of 10$^\mathbf{o}$C/min, and nitrogen flow rate of 50 ml/min. The dehydration process occurs at temperatures from 40 - 100^{0}C, while for thermal degradation at temperatures from 200 - 340$^\mathbf{o}$C, 400-500$^\mathbf{o}$C, and 580 - 670^{0}C. Activation energy and calorific value of RH with PB mixture increase significantly with the addition of 10%, 30%, and 50% PB in RH. It is concluded that pyrolysis characteristic of RH with PB mixture is better as fuel for power generation if compared with its original state.

1. Introduction

Fossil fuel consumption in Indonesia recorded a high value of approximately 95% in 2011. The use of oil is the largest portion of the total energy i.e. reaching up to 49.5%, where as coal and gas were in the proportion of 26% and 20.4%, respectively. Continuous utilization of fossil energy sources particularly oil, natural gas and coal will result in an expected deflection of these resources approximately 23, 55, and 83 years from the year 2011, respectively. The same time, electrification ratio in Indonesia was recorded at 72.95%, which meant that there were still 27.05% of households that did not receive electricity, especially in remote areas [1]. These conditions prompt optimization on renewable energy consumption in order to meet the needs for electrical energy, which also implies that the availability of electrical energy in Indonesia is still lacking. Base on previous studies result [2-3] show Indonesia has a great potential of rice husk (RH) is about 13.81×10^6 tons in 2013 with an energy potential of approximately 53,702 GWh. the CV of RH about 13.44 MJ/kg is within the range of 13 - 16 MJ/kg [4]. Meanwhile, the potential of plastic solid waste (PSW) of about 693 tons with energy potential of 28,752,528 MJ, equivalent to 1,065 tons of coal or 593 ton of oil. PSW, specially plastic bags (PB) has great energy with a calorific value (CV) of about 41.2 MJ/kg. This value is within the range of 39.03 – 41.5 MJ/kg [5]. Pyrolysis methods have received much

---

[4] To whom any correspondence should be addressed.

attention because these methods have the potential in reducing the volume of waste, recovery of various chemicals and as replacement for fossil fuels [6].

2. Materials and methods

2.1. Materials
The sample of PB was dried in an oven at a temperature of $105^{o}C$ for 1 hour and 7 hours for RH, as from previous studies [7-9]. The PB and RH mixture was sieved to obtain homogeneous sizes within the range of 0.125 - 0.3 mm to allow for an even mix, as in previous studies [10]. The sample was mixed with the following mass ratios of RH to PB: 90% RH: 10% PB (R_9P_1), 70% RH: 30% PB (R_7P_3) and 50% RH: 50% PB (R_5P_5).
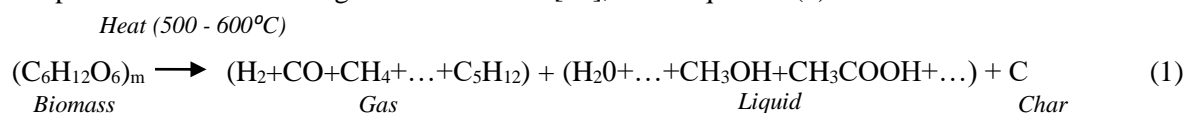
2.2. Proximate and ultimate analysis
Testing characteristics of the sample is done with proximate and ultimate analysis bese on previous studies [9]. The CV was obtained by using a bomb calorimeter, model IKA C 2000, according to DIN 51900 methods. The proximate analysis was done according to standard methods i.e. ASTM D3175, ASTM D 3172, ASTM D3173 and ASTM D3174. The ultimate analysis of the samples was done according to standard methods, i.e. ASTM D 4239, ASTM D 3176, and ASTM D 5373 as in previous studies [11-12].

2.3. Thermogravimetric analysis
Thermogravimetric analysis was conducted using the TGA/SDTA851, Mettler Toledo to analyze pyrolysis studies. The heating rates were controlled at $10^{o}C/min$ from 30 - $800^{o}C$. The pyrolysis process used nitrogen flow rate of 50 ml/min as previous studies [9, 13-15]. The dehydration process and thermal degradation on pyrolysis process were analyzed using TGA and DTG curves with the *Sma4Win software.*

2.4. Kinetics study
Kinetic study on pyrolysis process was done to investigate firstly the dehydration process (DP) from 40 - $100^{o}C$, thermal degradation (TD) of hemicelluloses from 200 - $260^{o}C$ and followed by cellulose from 240 - $340^{o}C$ and finally lignin from 280 - $500^{o}C$. The pyrolysis reaction is complete as the temperature reaches the range of 500 - $600^{o}C$ [16], as in equation (1):

Heat (500 - 600 ^{o}C)

$$(C_6H_{12}O_6)_m \longrightarrow (H_2+CO+CH_4+\ldots+C_5H_{12}) + (H_2 0+\ldots+CH_3OH+CH_3COOH+\ldots) + C \qquad (1)$$
Biomass   *Gas*   *Liquid*   *Char*

The degradation of hemicelluloses, cellulose and lignin in RH were approximately 30 - 35%, 21 - 31%, and 4 - 19%, respectively [16-17]. The kinetics of the degradation reactions are largely described by the first-order Arrhenius law. Activation energy (Ea) that occurs at every TD process can be obtained from the linear regression equation of the Arrhenius law [9-10, 14-15] as shown in the following equation:

$$k = Ae^{(-Ea/RT)} \qquad (2)$$

where; Ea is the activation energy for the reaction (J/mol), A is the pre-exponential factor (min^{-1}), R is the gas constant (8.314 J/K mol), T is the absolute temperature (K). The equation can be written in logarithmic form:

$$\ln k = \ln A - (\frac{Ea}{RT}) \ln e, \, where \, \ln e = 1 \qquad (3)$$

$$\ln k = -\frac{Ea}{R} \times \frac{1}{T} + \ln A \tag{4}$$

Based on previous studies [9, 13] the following equations are obtained:

$\ln k = -\ln[\frac{\ln(1-\alpha)}{T^2}]$ and $\ln A = \ln \frac{AR}{\beta E}$. Thus, equation (5) can be written as:

$$-\ln[\frac{\ln(1-\alpha)}{T^2}] = \frac{E}{R} \times \frac{1}{T} + \ln \frac{AR}{\beta E} \tag{5}$$

where; β is the heating rate (K/min), the mass loss fraction α for every stage of the thermal degradation is defined as:

$$\alpha = \frac{Mi - Ma}{Mi - Mf} \tag{6}$$

where; α is mass loss fraction (mg), M_i is the initial mass of the sample at the beginning of the reaction (mg), M_a is the actual mass of the sample (mg), M_f is the mass after pyrolysis of the sample (mg). The Ea may then be extracted from a plot of ln k vs. 1/T, which should be linear. This plot is known as the "Arrhenius plot". It is often symbolized by the linear regression equation: y = mX + b. Thus, the $-\ln[\frac{\ln(1-\alpha)}{T^2}]$ as y-axis, $\frac{1}{T}$ as x-axis, m = $\frac{E}{R}$ as slope, and b = $\ln \frac{AR}{\beta E}$ as the intercept of the line with y-axis.

3. Results and discussion

3.1. Characteristic of fuels

The results of proximate and ultimate analysis are presented in Table 1, which shows the characteristic parameters of the fuel. The CV of RH is 13.44 MJ/kg; the addition of PB 10%, 30% and 50% into RH increases the CV of R_9P_1, R_7P_3, and R_5P_5 to approximately17.85 MJ/kg, 23.97 MJ/kg and 28.93 MJ/kg, respectively. Meanwhile, VM, C and H increases with the amount of percentage of PB into RH. In contrast, the percentage of O, S, N, FC, MC, and ash decreased with the increase of PB percentage. The addition of PB into RH can improve the quality of fuel as such CV and VM increase whereas MC, S, N and ash decrease. Small amounts of N will reduce NO_x emissions into the air while small amounts of S can reduce or minimize pollution and corrosion.

Table 1. Test result on calorific value, proximate and ultimate analysis of RH and PB.

Parameters	Unit	RH	R_9P_1	R_7P_3	R_5P_5	PB
Calorific value (CV)	(MJ/kg)	13.44	17.85	23.97	28.93	41.21
Proximate Analysis						
a. Fixed carbon (FC)	(%)	14.81	13.62	10.89	8.00	0.72
b. Volatile matter (VM)	(%)	55.62	58.65	65.21	72.39	89.04
c. Moisture content (MC)	(%)	10.46	9.68	7.53	5.26	0.22
d. Ash	(%)	19.11	18.05	16.37	14.35	10.02
Ultimate Analysis						
a. Carbon (C)	(%)	37.48	40.21	47.00	53.60	67.49
b. Hydrogen (H)	(%)	5.08	5.82	7.10	8.61	10.25
c. Oxygen (O)	(%)	37.81	35.45	29.13	23.08	11.92
d. Nitrogen (N)	(%)	0.43	0.38	0.31	0.28	0.26
e. Sulfur (S)	(%)	0.09	0.09	0.09	0.08	0.06
f. Ash	(%)	19.11	18.05	16.37	14.35	10.02

3.2. Thermal degradation of pyrolysis

The pyrolysis result of RH, PB, R_9P_1, R_7P_3, and R_5P_5 can be seen the TGA curve, which was obtained using the *Sma4Win software* as shown in Fig. 1. The pyrolisis process for RH occurs at temperatures from 40°C - 100°C for dehydration process (DP) and 250°C - 390°C for (TD process), whereas PB occurs at a temperature range from 380°C - 500°C and 620°C - 680°C without the DP because PB is a non-polar material. Meanwhile, for the pyrolysis process of R_9P_1, R_7P_3, and R_5P_5, the TD occurs at temperatures from 40°C - 100°C, 250°C - 390°C, 400°C - 510°C, and 580°C - 680°C.
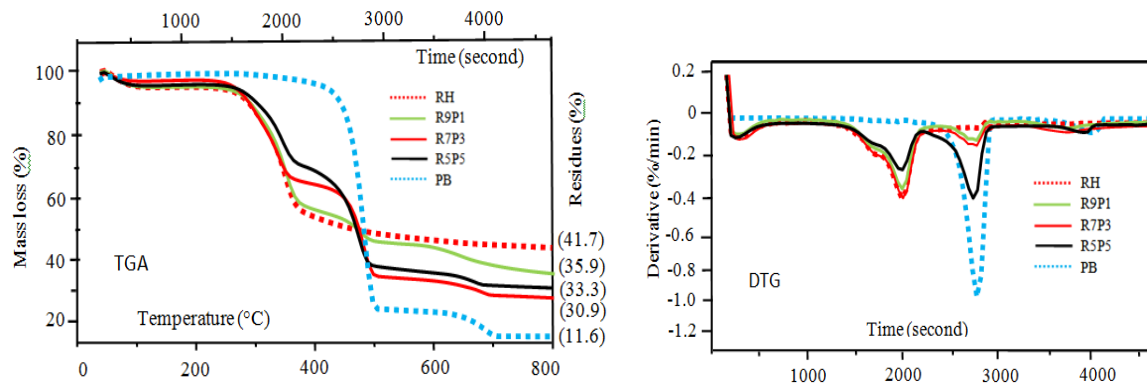

Figure 1. TGA and DTG curve of RH, R_9P_1, R_7P_3, R_5P_5, and PB for pyrolysis at heating rate of 10°C/min, temperatures range of 30°C - 800°C, and nitrogen flow rate of 50 ml/min.

Table 2 shows the pyrolysis process of RH in DP occurs in the temperature range of 40°C - 100°C with a mass loss (ML) of about 5.5%. The TD process zone 1 (TDZ 1) occurs in the temperature range of 250°C - 390°C with ML of about 52.8%, which is volatile to produce energy. Thus, the remaining mass of the char residue is approximately 41.7%. The pyrolysis process of R_9P_1, R_7P_3, and R_5P_5 in zone 1 showed the TD occurs in the temperature range of 250°C - 390°C with a ML of about 42.5%, 35.8% and 27.6% (respectively), which is volatile to produce energy. This is in contrast to the TDZ 2, where mass loss (energy released) of R_9P_1, R_7P_3, and R_5P_5 becomes greater   with the increase in percentage of PB in to RH i.e. about 11.4%, 22% and 31.4%, respectively and occurs in the temperature range from 420°C - 510°C.

Table 2. The parameter results of kinetic study for pyrolysis.

Fuels	SM (mg)	DP		TDZ 1		TDZ 2		TDZ 3		Char residues (%)
		ML (%)	T (°C)	ML (%)	T (°C)	ML (%)	T (°C)	ML (%)	T (°C)	
RH	5.6	5.5	40 – 100	52.8	250 – 380	-	-	-	-	41.7
R_9P_1	5.4	4.8	40 – 100	42.5	250 – 390	11.4	420 - 490	5.2	580 – 680	35.9
R_7P_3	5.5	4.5	40 – 100	35.8	260 – 390	22.0	420 - 510	4.4	600 – 660	33.3
R_5P_5	5.4	4.4	40 – 100	27.6	260 – 370	31.4	400 - 500	5.7	600 – 670	32.9
PB	5.6	-	-	79.7	380 – 500	8.8	620 - 680	-	-	11.6

The TDZ 3 occurs in the temperature from 580°C - 680°C with mass loss of about 5.2%, 4.4%, and 5.7%, respectively. Similarly, the TDZ 3 occurs for R_9P_1, R_7P_3, and R_5P_5 in the temperature range of 580°C - 680°C, 600°C - 660°C, 600°C - 670°C, with mass loss of 5.2%, 4.4%, and 5.7%, respectively. In total, the pyrolysis of R_9P_1, R_7P_3, and R_5P_5 where ML occurs about 64.1%, 66.7%, and 67.1%; therefore, the char residues generated is about 35.9%, 33.3%, 32.9%, respectively. This shows smaller

ash content with the increasing percentage of PB in the fuel. These characteristics indicate that the use of R_9P_1, R_7P_3, and R_5P_5 as fuels requires minimum temperatures of 680^0C.

3.3. Kinetic parameters analysis

The linear regression of the Arrhenius equation of pyrolysis for RH, R_9P_1, R_7P_3, R_5P_5, PB at every stage of TD was obtained using Microsoft Excel. Based on the TD occurred at temperatures from 250^oC - 390^oC was obtained $Ea_1 = 57.01$ kJ/mol based on the linear regression equation: $y_1 = 6857x + 2.144$, $R^2 = 0.99$. The linear regression curve of R_9P_1 is presented in figure 2 (a). By the same method, the linear regression equation and Ea according to Arrhenius can be obtained for R_7P_3 and R_5P_5 as shown in Figs. 2B and 2C. Similarly, the linear regression curve for RH and PB can be obtained by the same method.
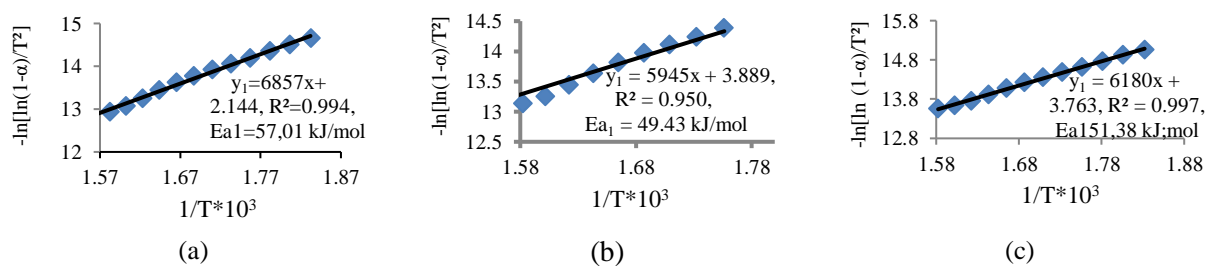

Figure 2. The linier regression curve of (a) R_9P_1, (b) R_7P_3, and (c) R_5P_5 for pyrolysis.

Based on the analysis of kinetic studies, the determination of Ea for each TD was conducted based on the linear regression equation. The value of R^2 shows the relationship between variables x and y. The linear regression equation can be used to determine the value of Ea when $R^2 > 0.9$. The results of PB pyrolysis gave Ea of about 255.5 kJ/mol, which is relatively large if compared with the Ea of RH, which is only 52 kJ/mol. The PB addition of approximately 10%, 30% and 50% into RH improve the Ea of R_9P_1, R_7P_3, and R_5P_5. The linear regression equation, Ea value in pyrolysis process for RH, R_9P_1, R_7P_3, and R_5P_5, PB is presented in table 3.

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

Fuels	TD (°C)	A	Linier regression	(R^2)	Ea (kJ/mol)			
					Ea_1	Ea_2	Ea_3	Total
RH	250 – 380	0.11-0.79	$y_1 = 6934x + 1.763$	0.99	57.7	-	-	57.7
R_9P_1	250 – 390	0.12-0.65	$y_1 = 6857x + 2.144$	0.99	57.1	-	-	-
	420 – 490	0.72-0.85	$y_2 = 1889x + 10.22$	0.91	-	15.7	-	-
	580 - 680	0.80-0.97	$y_3 = 1908x + 10.62$	0.96	-	-	15.9	88.6
R_7P_3	260 – 390	0.14-0.60	$y_1 = 5945x + 3.889$	0.95	49.4	-	-	-
	420 – 510	0.64-0.92	$y_2 = 5194x + 5.728$	0.92	-	43.2	-	-
	600 - 660	0.95-0.98	$y_3 = 1870x +10.35$	0.93	-	-	15.6	108.2
R_5P_5	260 – 370	0.08-0.4	$y_1 = 6180x + 3.763$	0.99	51.4	-	-	-
	400 – 500	0.50-0.83	$y_2 = 7127x + 3.293$	0.91	-	59.3	-	-
	600 – 670	0.93-0.98	$y_3 = 4695x + 7.394$	0.93	-	-	39.0	149.7
PB	380 – 500	0.01-0.87	$y_1= 25430x - 20.44$	0.99	211.4	-	-	-
	620 – 680	0.92-0.97	$y_2 = 5296x + 6.935$	0.97	-	44.1	-	255.5

Based on data analysis, the pyrolysis process showed greater content of plastic in the sample, produces a large and increasing the Ea and the residues were getting smaller. This is due to plastic has a CV and VM are large with a small ash residue.

4. Conclusion

Pyrolysis characteristics of RH with PB shows an increase in activation energy, calorific value, volatile matter, and carbon content. On the contrary, ash, nitrogen, sulfur, and moisture show a decrease. The addition of PB into RH increases the activation energy and calorific value of R_9P_1, R_7P_3, and R_5P_5, and reduced char residues, significantly. Pyrolysis results of RH and PB showed improve the thermal characteristics of the RH for improving the performance, resulting in large energy release and lowers the ash residue. Pyrolysis results of RH and PB show feasibility in the implementation as an alternative energy source as fuel in power generation.

5. Acknowledgement

6. References

[1]   Directorate of Energy and Minerals Resources 2012 Alignment of National Energy Policy (KEN) with the General Plan National Energy (RUEN) *Policy paper*

[2]   Anshar M, Kader A S and Ani F N 2014 The utilization potential of rice husk as an alternative energy source for power plants in Indonesia *Advanced Materials Research, Trans Tech Publications, Switzerland* **845** 494-498

[3]   Anshar M, Ani F N and Kader A S 2017 Co-Combustion Modeling Of Rice Husk And Plastic Bag As Energy Source In Indonesia *Asian Research Publishing Network (ARPN) J. of Eng. and Applied Sci.* **12**(10) 3105-11

[4]   Rozainee M, et al. 2008 Fluidized bed combustion of rice husk to produce amorphous siliceous ash *Energy for Sustainable Development* **12**(1) 33-42

[5]   Anshar M, Ani F N and Kader A S 2015 The potential energy of plastic solid waste as alternative fuel for power plants in Indonesia *Applied Mech. and Materials, Trans Tech Publications, Switzerland* **699** 595-600

[6]   Chattopadhyay J, et al. 2008 Thermogravimetric characteristics and kinetic study of biomass co-pyrolysis with plastics *Korean J. Chem. Eng.* **25**(5) 1047-53

[7]   Yuan S, et al. 2012 Rapid co-pyrolysis of rice straw and a bituminous coal in a high-frequency furnace and gasification of the residual char *Bioresource Technol.* **109** 188–197

[8]   Xie Z and Ma X 2013 The thermal behaviour of the co-combustion between paper sludge and rice straw *Bioresource Technol.* **146** 611–618

[9]   Anshar M, Ani F N and Kader A S 2017 Co-pyrolysis of rice straw with high density polyethylene bag *Chiang Mai J. Sci.* **44**(3) 9877-79

[10]   Chen D, Zheng Y and Zhu X 2013 In-depth investigation on the pyrolysis kinetics of raw biomass. Part I: Kinetic analysis for the drying and devolatilization stages *Bioresource Technol.* **131** 40–46

[11]   Maiti S, et al. 2006 Physical and thermochemical characterization of rice husk char as a potential biomass energy source *Bioresource Technol.* **97** 2065–70

[12]   Sait H H, et al. 2012 Pyrolysis and combustion kinetics of date palm biomass using thermogravimetric analysis *Bioresource Technol.* **118** 382–389

[13]   Said M M, John G R and Mhilu C F 2014 Thermal characteristics and kinetics of rice husk for pyrolysis process *Int. J. of Renewable Energy Research* **4**(2)

[14]   Kumar S and Singh R K 2014 Pyrolysis kinetics of waste high-density polyethylene using thermogravimetric analysis *Int. J. of Chem Tech Research* **6(1)** 131-137

[15]   Chattopadhyay J, et al. 2008 Thermogravimetric characteristics and kinetic study of biomass co-pyrolysis with plastics *Korean J. Chem. Eng* **25**(5) 1047-53

[16]   Yokoyama S 2008 The Asian Biomass Handbook, *A Guide for Biomass Production and Utilization* (Japan: The Japan Institute of Energy)

[17]   Zhou H, et al. 2013 The pyrolysis simulation of five biomass species by hemi-cellulose, cellulose and lignin based on thermogravimetric curves *Thermochimica Acta* **566** 36-43