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Influence of temperature on conversion of plastics waste (polystyrene) to liquid oil using pyrolysis process

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Abstract. Plastic waste has been a problem in waste treatment.The growth of plastic waste is increasing especially in Jakarta and needs more serious attention in waste processing. To convert polystyrene to be liquid much heat energy is needed. In this research, pyrolysis is used as the method to process polystyrene to be aliquid product. The objective of this research is to obtain the characteristics of the heating process, and the properties of the liquid product. This liquid can be used as a fuel. Fixed-bed reactor with SUS 316L as the base material was constructed to decompose the polystyrene using an electric heater, which was controlled using Digital PID controller. Power sensor was mounted in the electrical circuit to monitor the power that entered to the heater and recorded using data acquisition. The reaction temperature was varied from 350 °C – 550 °C. No sweep gas injected into the system. The vapor flows naturally based on their partial pressure. The temperature of cooling water was varied into two conditions, water ambient temperature, and cold water. To condense pyrolysis vapor to be liquid oil, the double-pipe condenser was constructed. The thermocouples were installed at many points of the system to monitor temperature change in the system. The maximum liquid yield was obtained at reaction temperature 500 °C with cooling water temperature at 16.59°C.The operating temperature Below 500 °C will produce more wax, and above 500 °C will produce much gas. The liquid can be applied as fuel with heating value 43.83 mJ/kg, density 0.89 g/ml and0.78 cSt of kinematic viscosity.

1. Introduction

DKI Jakarta as the capital city of Indonesia becomes the center of activities and population in Indonesia. So, some people from other provinces move to Jakarta. Together with the increase of population in Jakarta, the consumption, and production of plastics increases. Waste volume in Jakarta is 7000 ton/day and predicted to keep growing each year [1].

Generally, there are three ways to manage plastic waste which is landfilling, incineration with or without energy recovery and recycling[2]. The incineration will increase the emission of harmful gases, e.g.NO_x, SO_x, dan CO_x[3]. The most commonly used method for energy recovery is thermal cracking (Pyrolysis). Pyrolysis process is one of the finest techniques for the conversion of mass to liquid and gaseous products with high energy values [4]. Previous researches have been carried out to convert plastic wastes into oil by means of the pyrolysis process. Temperature has a strong effect on

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the characteristics of pyrolysis liquid, such as viscosity and hydrocarbon chain [5].The pyrolysis process is carried out at the temperature between 300°C to 600°C [6]. Pyrolysis processes are influenced by the reaction temperature, residence time, heat rate and the composition of raw material [7]. Polystyrene has been a good raw material to convert into fuel [8].The reaction temperature needed to degrade this material into vapor and liquidbetween 350 °C-480 °C[9].

M. Artetxeet al, was used spouted reactor to enhance styrene monomer recovery, the liquid yield was influenced by nitrogen flow rate and temperature [10]. The effect of the reaction time and temperature on the liquid yield and quality were investigated. Nitrogen was flowed into the reactor and the vapor was condensed in the condenser using chiller water with low temperature[11]. The aims of this research areto obtain the characteristics of the heating process experimentally in the reactor with natural flow, and the properties of the liquid product with polystyrene as raw material.

2. Materials and methods

2.1. Sample preparation

Polystyrene (PS) plastic was used as feedstock in the thermal pyrolysis process to produce liquid oil, non-condensable gas, and wax. 30 g of PS samples were used for each experiment and it was weighed using digital scales with 0.001 g of accuracy. The raw material (PS plastic waste) was prepared by cutting it into small pieces around 1-2 mm^2, thickness 1-2 mm, and moister content below 10%.

2.2. Experimental setup

A fixed bed pyrolysis reactor was commissioned and used for the conversion of plastic waste into pyrolysis vapor and wax. The reactor was made of stainless steel and covered with an electric heater capacity 20 A and 220 V that allows achieving a maximum temperature of 650 °C. The temperature of the electric heater was controlled by Proportional-Integral-Derivative (PID) digital controller to manage the constant temperature at the outer diameter of the reactor as seen in figure 1. The height of the reactor was 250 mm with 73.6 mm inner diameter and 88.9 mm outer diameter.

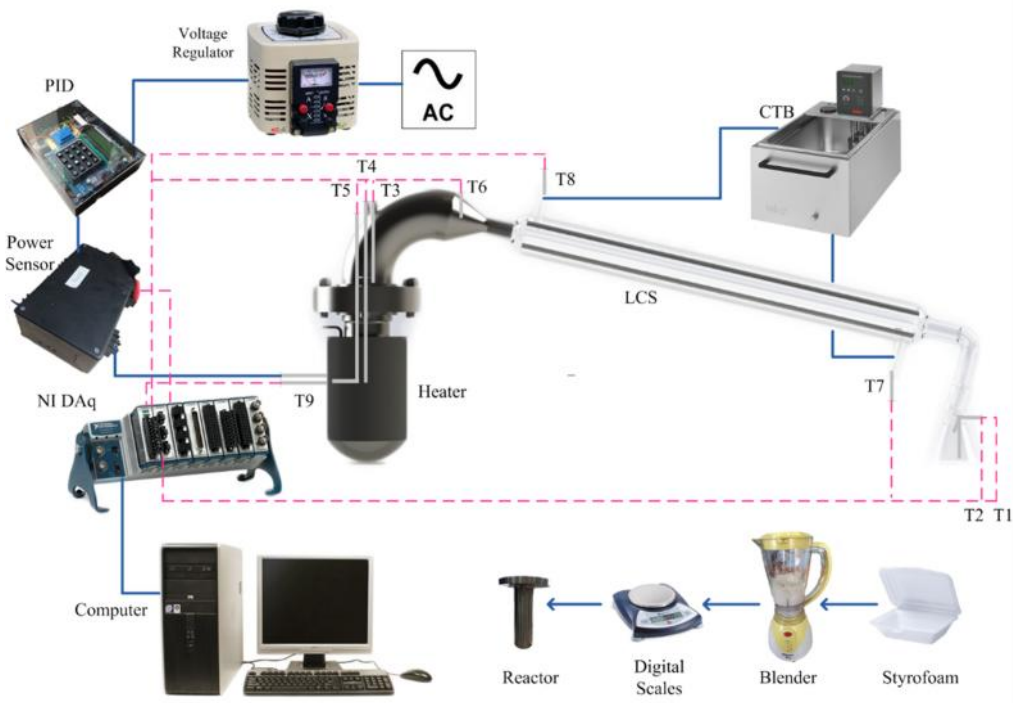


Figure 1. Experimental setup.

A double pipe type condenser as heat exchanger was made from Pyrex material named as liquid collection system (LCS) with water as the cooling fluid to condense the pyrolysis vapor into liquid. The use of Heat exchanger will easier to control the temperature and to separate the heavy and light fraction in liquid collection system [12]. The feedstock was converted into vapors, which were condensed into liquid oil after passing through the condenser and collected in the collection tank at the bottom. The vapor was condensed by using varied temperature which is cold water around 15-17℃ and ambient temperature of the water around 28-30 ℃. K-type thermocouple was used to measure the temperature of the system. The thermocouple accuracy was 0.1 ℃. Each sample of PS was heated in the pyrolysis reactor from room temperature to a varied wall temperature of 350°C, 400°C, 450°C, 500°C, and 550°C respectively. The fractions of liquid oil, non-condensable gas (NCG), and wax were estimated on their weight basis. The yield of liquid oil was further characterized to study the characteristics and its compositions. The compositions were analyzed by GC.MS Agilent 7890A, column DB-5MS. The GC oven temperature is maintained at 40^0C for 4 minutes and is programmed to rise to 300^0C with the rate of 10^0C/min kept for 8 minutes. The carrier gas used was Helium.

3. Result and discussion

3.1. Effect of pyrolysis, vapor and cooling water temperature to yield percentages of product liquid

Yield percentage of product liquid due to pyrolysis temperature and cooling fluid temperature are shown in Table 1. The maximum liquid yield 84.4% was obtained on pyrolysis wall temperature at 500 ℃ with cooling fluid using cold water at temperature 16.59 ℃ and heating rate 28.76(°C/min).

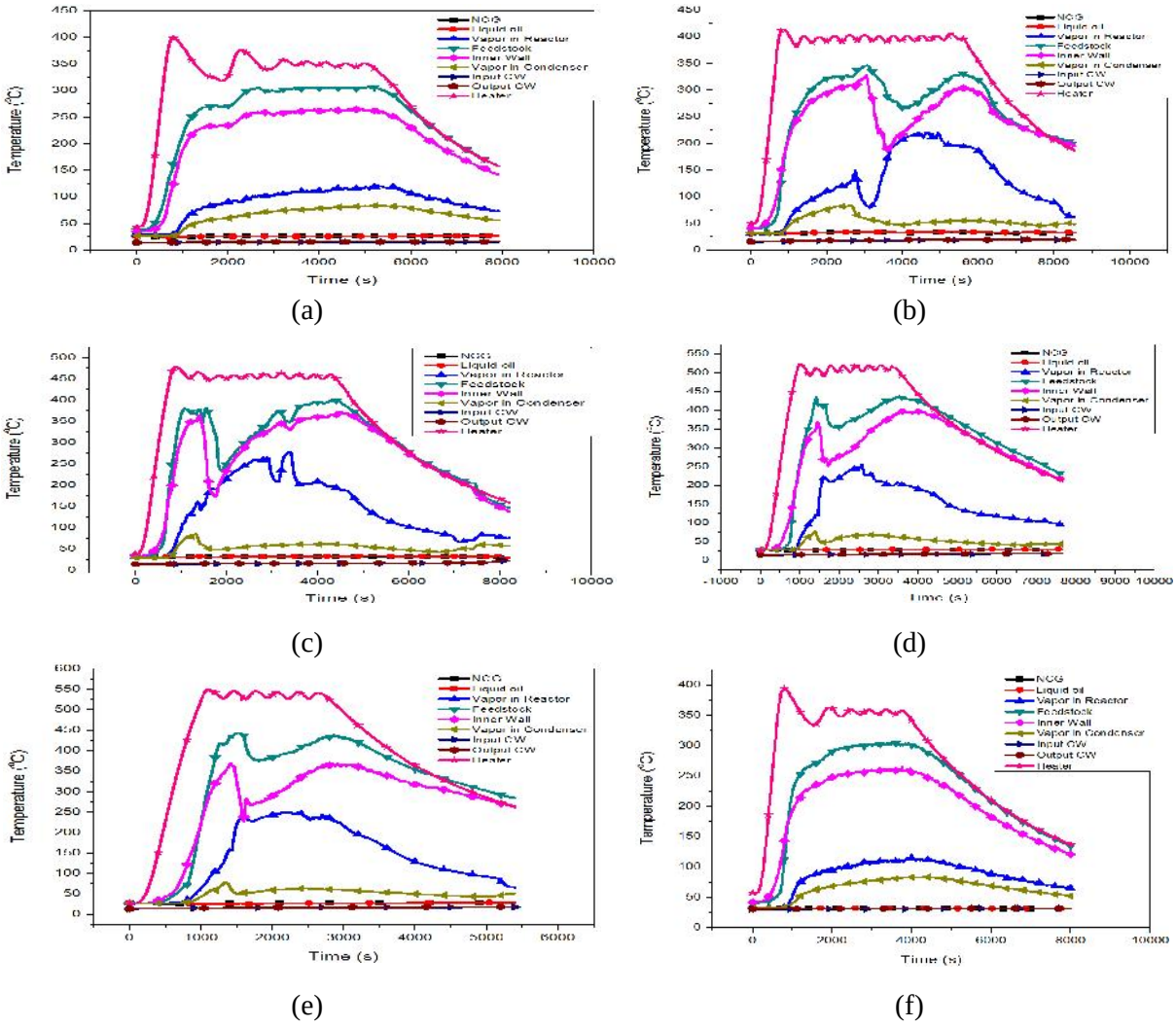
Table 1. Comparison of different pyrolysis temperature for product yield.

Mark	Pyrolysis temperature(°C)	Water temperature of LCS (°C)	Power (kWh)	Heating-rate(°C/min)	Product Yield (wt%)		
					Liquid	Wax	NCG
(a)	350	15.40	1.04	29.13	7.11	70.69	22.20
(b)	400	16.96	0.85	30.85	24.99	52.71	22.30
(c)	450	16.15	0.86	31.14	63.82	2.50	33.67
(d)	500	16.59	1.35	28.76	84.80	7.63	7.57
(e)	550	16.93	1.27	27.83	56.59	5.67	37.73
(f)	350	31.18	0.86	31.34	5.88	72.72	21.41
(g)	400	25.48	0.79	29.20	24.86	42.95	32.19
(h)	450	26.28	0.84	30.06	60.77	8.36	30.87
(i)	500	26.58	1.04	28.13	79.17	4.97	15.86
(j)	550	29.37	1.23	29.29	52.04	2.39	45.56

Meanwhile, the temperature distribution of pyrolysis process using PS as raw material shown in figure 2. The processes were done by various heating temperatures using cold water and ambient temperature of water. In the pyrolysis process, PS as the raw material is decomposed by using heat to produce vapor and convert it into liquid oil, non-condensable gas, and wax. We focused on the optimum liquid oil production from several heatingtemperatures using cold water and ambient temperature of water. In figure 2 also shows the chart that shows distribution temperature of the noncondensable gas, liquid product, vapor in the reaction zone, raw material, and vapor in the condenser zone, input and output of cooling water and outside wall (heater). Figure 2 (a) shows the distribution temperature on pyrolysis process at reaction temperature 350 °C. Outside wall temperature was maintained to remain constant at this temperature using PID controller. In this process, the yield liquid product was 7.11%, polystyrene did not decompose completely at this temperature [13, 14]. The yield dominant product was wax 70.69%, and the vapor temperature was below 100 ℃. Meanwhile, the Figure 2(b), 2(c), 2(d) and 2 (e) shows distribution temperature of pyrolysis process at

400 °C, 450 °C, 500 °C and 550 °C respectively using cold water as cooling fluid. Starting from reaction temperature at 400 °C, vapor temperature increased and indicated to produce much vapor. Reaction temperature at 500 °C produced maximum liquid yield. The reaction temperature above 500 °C produced more gases. Some of the vapor, which has low boiling point temperature was condensed at the reaction zone. This phenomenon was indicated with a sudden drop of vapor temperature. The maximum liquid yield using ambient temperature of cooling water was 79.17%. There is a liquid yield reduction around 5.63% when using ambient temperature of water compared to cold water as cooling fluid.

Figure 3 shows the stacked column as the comparison between liquid, wax and NCG product yield due to outside wall temperature. The maximum liquid was obtained at the temperature of 500 °C, either using cold water or ambient temperature of the water as cooling fluid. The quantitative data in the stuck column comes from t table 1.



(a) (b)

(c) (d)

(e) (f)

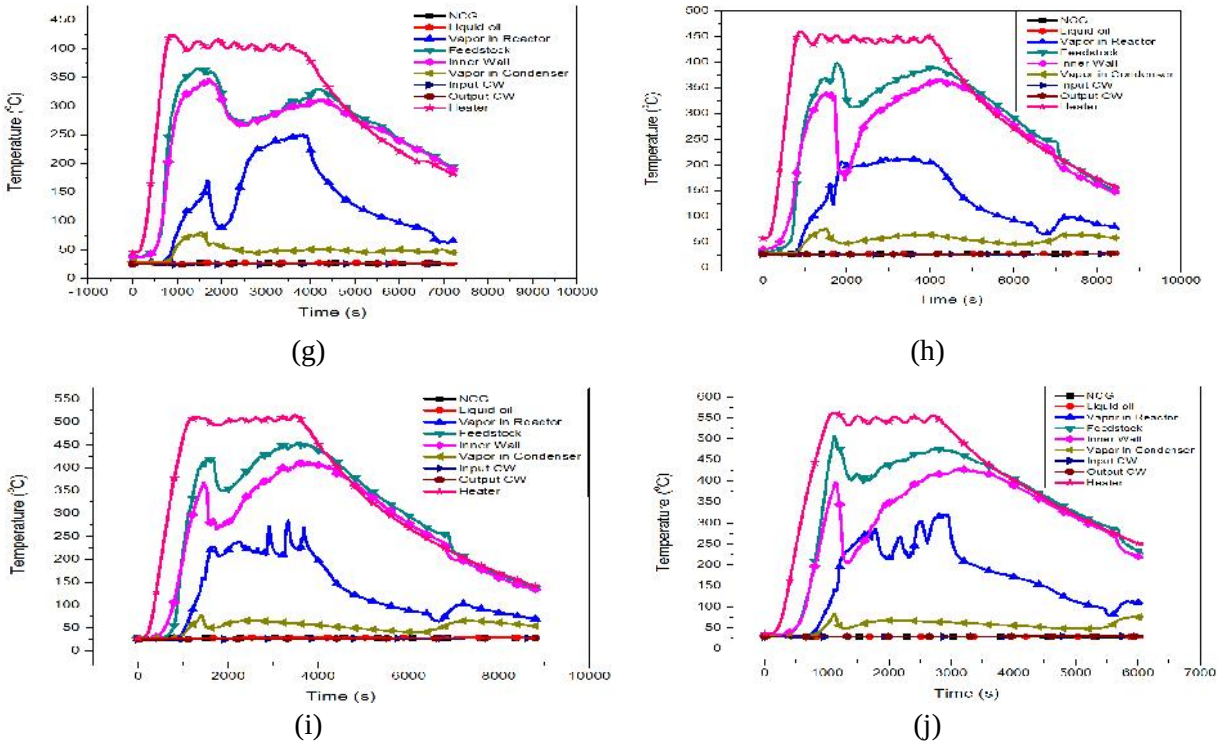


Figure 2.Temperature distribution in pyrolysis process using cold water as cooling fluid and wall temperature at (a)350 °C, (b) 400 °C, (c) 450°C, (d) 500 °C, and (e) 550 °Cand using ambient temperature at (f) 350 °C, (g) 400 °C, (h) 450°C, (i) 500 °C, and (j) 550 °C.

There is no significant difference in liquid yield on the use of cold water or regular water, but reaction temperature becomes the main factor in determining the liquid yield.

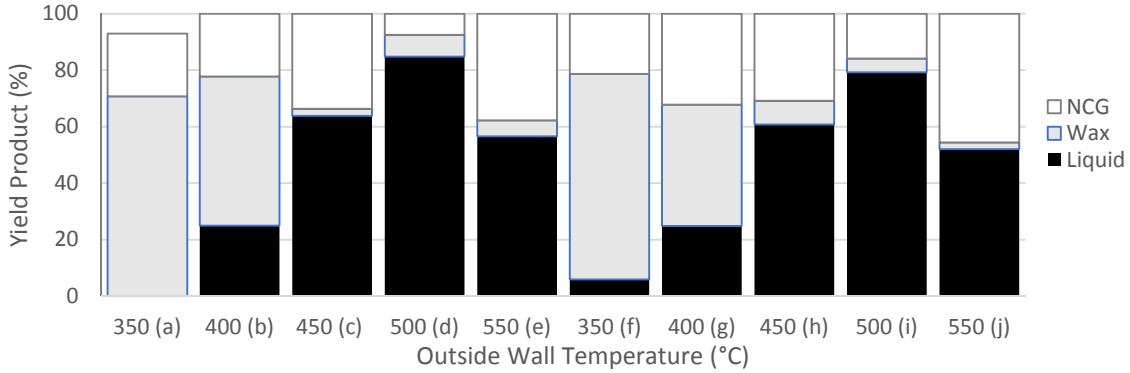


Figure 3.Yield product percentage for each outside wall temperature.

The characterization of liquid product has been conducted to obtain physical properties, such as density, viscosity and heating value. The sample was taken for the maximum liquid yield. The density is the most important parameter for crude oil product [14], low density will consume more fuel and will damage the engine[15]. Heating value is a significant parameter and must be measured in the liquid oil. This value determines the amount of energy released when a fuel is completely burned [15]. Characterization of liquid oil can be seen in table 2. This characteristic of heating value is identical to the character of diesel fuel, that is 43.0 mJ/kg[16]. The chemical compound and content percentage in liquid oil were measured using GC-MS as shown in table 3.

Table 2. Characterization of liquid oil.

No	Characteristic	Result	Unit
1	Density	0.89	g/ml
2	Viscosity at 40°C	0.78	cSt
3	Heating Value	43.83	mJ/kg

Table 3. The chemical compound of liquid oil measured using GC-MS.

No	Retention Time	Compound	% Area	Molecular Formula
1	4.44	Toluene	9.53	C_7H_8
2	6.788	Ethylbenzene	3.96	C_8H_{10}
3	7.804	Benzocyclobutene	60.33	C_8H_8
4	8.264	Isopropyl benzene	0.34	C_9H_{12}
5	9.04	Benzaldehyde	0.19	C_7H_6O
6	9.51	alpha.-Methyl styrene	14.33	C_9H_{10}
7	10.297	cis-beta-methyl styrene	0.15	C_9H_{10}
8	17.667	1,2-Diphenylethane	0.17	$C_{14}H_{14}$
9	19.266	1,3-Diphenylpropane	2.54	$C_{15}H_{16}$
10	19.555	p-Xylene	1.16	C_8H_{10}
11	20.031	3-Butynylbenzene	6.17	$C_{10}H_{10}$
12	20.186	1,2-	1.13	$C_{15}H_{14}$

4. Conclusion

Polystyrene has been used as raw material to produce liquid oil. Pyrolysis process was applied to convert polystyrene to be liquid,gas, and wax. The influence of temperature on conversion of plastics waste (polystyrene) to liquid oil using pyrolysis process and no sweep gas injected into the system has been investigated. . The maximum liquid was obtained at reaction temperature 500°Cand heating rate 28.76(°C/min). In this experiment The operating temperature Below 500 °C will produce more wax, and above 500 °Cwill produce much gas.The rendement at reaction temperature 500 °Cwas 84.80% base on their weight with cooling water temperature of 16.6 °C, and 79.17 wt% with ambient temperature of cooling fluid. The heating value of this liquid is 43.83 mJ/kg, density 0.89 g/ml and 0.78 cSt of kinematic viscosity.

5. Acknowledgments

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