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Performance of Automatic Temperature Control System in Pyrolysis Reactor of LDPE Plastic Waste

I Made Agus Putrawan[1 *], I Nengah Darma Susila[1], I Nyoman Suparta[1]

[1] Mechanical Engineering Department, Bali State Polytechnic
Kampus Politeknik Negeri Bali, Bukit Jimbaran, Kuta Selatan, Badung, Bali, Indonesia-80361

**Corresponding author: agusputrawan@pnb.ac.id* Doi: https://doi.org/10.24036/invotek.v23i3.1129

Abstract

Pyrolysis is a process of decomposing material at high temperatures without or with limited air and is an alternative waste treatment which is considered quite prospective to be developed. Plastic waste treatment as pyrolysis fuel, is strongly influenced by operating conditions, which consist of the thermal properties of plastics such as the LDPE type, which are still massively used in society. This research processes LDPE type plastic waste using technology fixed bed pyrolysis type batch reactor with a capacity of 0.01 m^3 with initial heating from external heat of LPG energy source. The pyrolysis process takes in a closed reactor and the mass flow rate of the condensate flows naturally to the condenser for the condensation process to become pyro-oil product. Optimization of the reactor pyrolysis was carried out by adding insulated heat cover to reduce heat losses during the heating process. The addition of automatic temperature control to regulate the heating rate, makes operation control easier and reducing fluctuations in temperature distribution during pyrolysis process. The research was carried out with three operating temperature variations of 250, 275, and 300 °C using 0.8 kg LDPE plastic waste for batch test. The performance of automatic temperature control was observed using a digital thermometer and a comparison of the results before and after installation was carried out at a temperature of 300 °C. The results showed that heating temperature control which was previously done manually gives fluctuating results with a temperature difference of up to 50 °C. With the addition of an automatic temperature control system, the operating temperature during the pyrolysis process shows relatively lower fluctuations with a maximum difference of 20 °C. The initial heating energy consumption from LPG and the fuel consumption rate (FCR) show an increase along with the increase in the pyrolysis operating temperature setting.

Keywords: Pyrolysis, Temperature, LDPE Plastic, Heat Cover, Automatic Control.

1. Introduction

Pyrolysis is a process of decomposition of organic material with heat without containing oxygen. The products that can be produced can be in the form of gas (H_2, CO, CO_2, H_2O, CH_4), tar and charcoal. Charcoal formed during the pyrolysis process can be used as fuel or used as activated carbon. While the liquid oil produced from the pyrolysis process can be utilized as an addictive substance or used for fuel mixtures [1].

A lot of works have been developed on pyrolysis in traditional reactors such as fluidized-bed [2], [3], fixed bed [4], [5], rotary kiln [6] reactors etc. Pyrolysis reactors have two important requirements for heat transfer: (1) to the reactor heat transfer medium (solid and gas in a fluid bed reactor or the reactor wall in an ablative reactor), (2) from the heat transfer medium to pyrolysis particles through convection, and solid-solid where conductive heat transfer occurs. About 90% of heat transfer in fluid bed reactors occurs by conduction, with a small contribution of convection heat transfer of up to 10% because of utilising good solid mixing. Along with convection and conduction, some radiation heat transfer also occurs in all types of reactors. However, several heating methods are used in different pyrolysis reactors to ensure the efficient conversion of biomass into liquid fuel [7].

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Plastic waste is a polymer compound with a very large molecular shape in which the main element is carbon. The term plastic, in a chemical sense, includes synthetic or semi-synthetic polymerization products. One type of plastic waste that is very easy to find is Low Density Polyethylene (LDPE). The derivative of this type of plastic is crackle plastic whose use is still very massive in the community so that its existence is quite abundant and is considered to have no economic value. Its main characteristics are that it is easy to process, easy to shape using heat, and is formed from petroleum-based materials. The physical properties of the liquid production from pyrolysis of waste plastic bag compared with diesel oil, which shows that it can be used as diesel oil substitution [8]. The results and quality of the pyrolysis product using plastic waste are highly dependent on the parameter setting such as temperature, reactor type, residence time, pressure, different catalysts usage and type of fluidizing gas with its flow rate [9].

One of the important parameters in the pyrolysis process is the heating temperature which is closely related to the material properties of the fuel used. The influence of the reactor heating temperature will have an impact on the production of gas yields and the composition of the liquid fraction which generally will contain larger aliphatic compounds at lower temperatures and aromatic compounds at higher temperatures [10]. The pyrolysis process requires initial heating energy and the problem of quite large heat loss from the furnace to the reactor. Previous research conducted on pyrolysis reactor design showed that the average temperature in the furnace was 665.61 °C and the average temperature in the reactor was 443.07 °C. There is quite a large heat loss of 222.54 °C from the furnace to the reactor [11]. To reduce heat losses that occur, it is necessary to add heat insulators to the reactor walls. Research from [12] was carried out to determine the effect of using a heat insulator from glasswool on the heat distribution of the pyrolysis reactor. The results show that the use of glass wool heat insulators affects the performance of reactor, the thicker use of glass wool heat insulator increases distillation efficiency and also technical efficiency. Other research was carried out by designing a pyrolysis reactor with a flame passage cover. The results show that the addition of the flame passage cover has an effect on the heat distribution of the pyrolysis reactor, increases the average reactor temperature, and reduces the temperature difference at each point of the reactor. The technical efficiency of the plastic waste pyrolysis process is 3.92% without using a flame passage cover and 5.98% using a flame passage cover [13].

There has been a lot of research to optimize the performance of pyrolysis reactors. However, further research that utilizes natural fibre from jute as an additional material for the heat insulator layer in pyrolysis reactors needs to be carried out. In addition, controlling the heating rate is needed to reduce temperature fluctuations over time and is easy to operate during the process. This research was carried out by adding a heat insulation cover from a layer of glass wool and jute fibre to reduce pyrolysis heat loss and adding an automatic temperature controller to regulate the heating rate in the pyrolysis reactor.

2. Research Methodology

2.1 Feed Stock Materials

This research processes LDPE type plastic waste produced from households such as plastic bags, snack wrappers, saran wrap, ziploc to be processed using a pyrolysis system. Thus, maintaining uniform characteristics, the plastic is separated from the impurities and cropped into equal sizes.

2.2 Fixed Bed Reactor

The application of fixed bed pyrolysis equipment with batch reactor type is designed for household scale with a maximum capacity of 0.01 m^3 which can treat crackle waste produced by households on average for 4 days. The reactor pyrolysis (diameter:260mm and high:250mm) was made from stainless steel having the fuel feeder (header heigh:100mm, diameter:50mm) at top of reactor. The pyrolysis reactor is designed with a thin-walled category with a thickness of 1.2 mm to maximize the external heating process which refers to the category of wall thickness as in the equation [14].

For a thin walled cylinder, $$t < \frac{1}{20}D \tag{1}$$

The addition of a heat cover as a heat-resistant material is made from a combination of glass wool and jute wool to reduce heat losses that occur during the reactor heating process. The outer layer of the

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reactor wall is coated using two main layers in the form of glass wool and jute. Glass wool is a thermal insulation material consisting of intertwined and flexible glass fibres, which causes it to "package" air resulting in high thermal insulation properties. The thickness of the first layer of glass wool is 25 mm [15]. Jute as a natural material has the advantage of being environmentally friendly and its use is still massive in society so it is easy to find. Jute with a thickness of 5 cm as insulation material is considered as green/sustainable material, which may replace a greater extent of synthetic material for the same application.

2.3 Experimental Setup

LDPE type plastic is fed into the batch type pyrolysis reactor through the feeder at the top of the reactor. The feeder valve is closed tightly to avoid gas leaks. The initial heating of the pyrolysis reactor begins with setting the heating temperature on the thermo setting control. Temperature control in the reactor is carried out using a solenoid valve gas regulator with an AC 220V voltage input which is controlled automatically by Omron E5CC-RX2ASM-800. Supply power: 100 to 240 VAC Control Output 1 relay 2 auxiliary output to regulator gas control. The temperature input comes from a type K sensor which is installed at the bottom of the reactor to read the temperature that occurs in the reactor. Temperature setting is done digitally by adjusting the temperature with the F_1 and F_2 settings. The F_1 setting is for setting the reactor temperature while F_2 is for setting the minimum temperature limit (of 2 °C). Heating occurs because there is an electric current to the solenoid valve which causes gas to flow from energy heat source LPG into the furnace. After the reactor temperature reaches the setting temperature, the control will cut off the electricity to the gas solenoid valve which causes the gas to stop flowing and heating to stop. After the temperature decreases by 2 °C, the control will restart the electric flow to the gas solenoid valve which causes gas to flow and the furnace will turn back on to heat the reactor. A pilot heating flame is used in the furnace to start the flame when there is a flow of LPG. The heating process will continue automatically by opening the gas flow if the temperature difference in the reactor is read different at 2 °C. The schematic system at Figure 1.

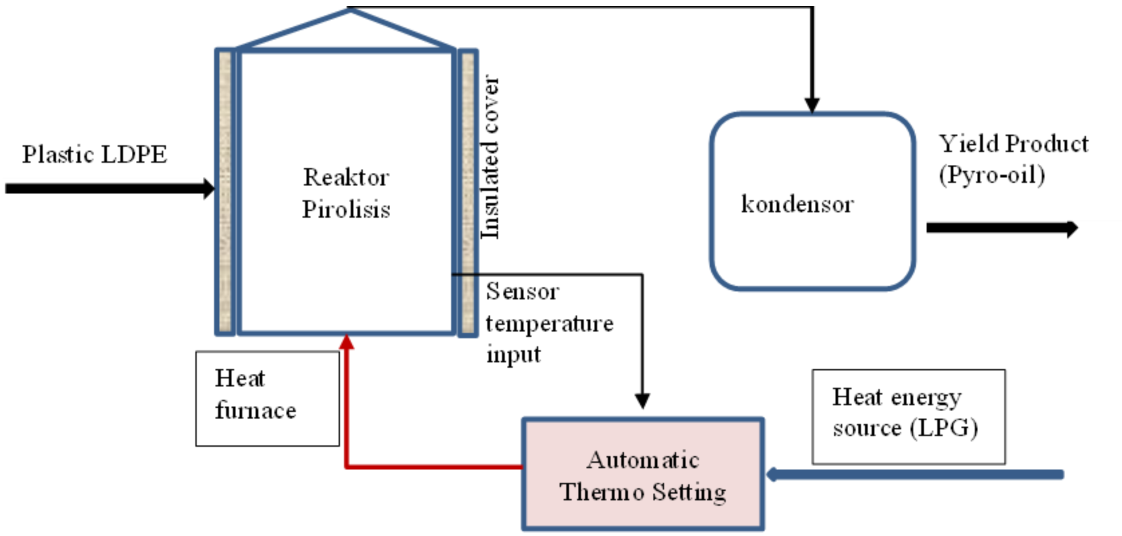

Figure 1. Pyrolysis Schematic with Automatic Temperature System

2.4 Reactor Temperature Distribution

Type K thermocouples with a diameter of 3 mm and a length of 200 mm are made from Mineral Insilite probe material which contains an insulator in the form of Magnesium oxide powder which is used to measure the temperature that occurs in the reactor. There are three thermocouples installed in the reactor at a distance of 50 mm from the bottom of the reactor, and 70 mm between thermocouples T_1, T_2 and T_3 as in the Figure 2. The temperature measurement results from the type K thermocouple are read using a digital temperature display which can also be recorded by a data logger to obtain a temperature distribution profile in the pyrolysis reactor.

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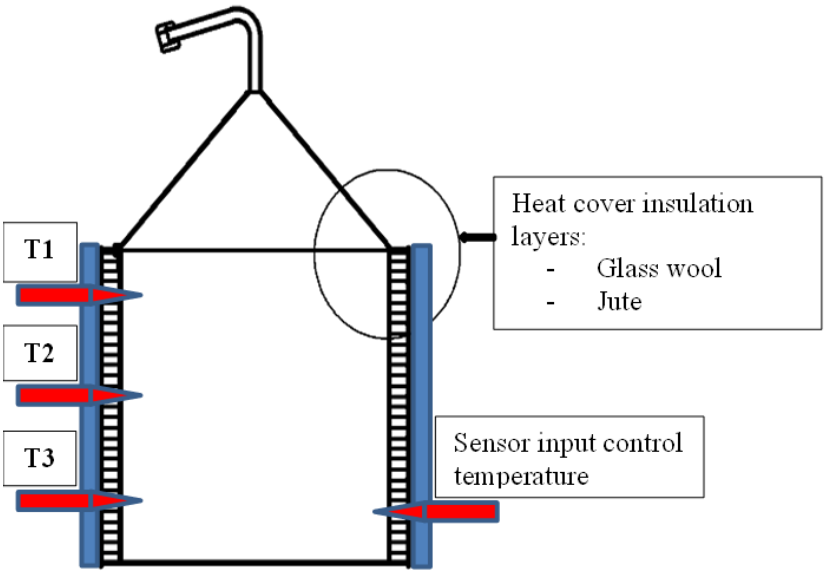

Figure 2. Temperature reactor sensors

Pyrolysis of LDPE plastic through a heating process with or without oxygen. It starts at around 200 °C when the thermally unstable components and volatile waste matter are broken down and evaporated along with the other components [16]. This research was carried out with 3 variations of reactor temperature at 250, 275, and 300 °C which refers to the properties of LDPE plastic waste [17]. The temperature distribution graph in the reactor before and after installing the heat cover in the pyrolysis reactor will be studied and compared at a temperature setting of 300 °C.

The performance of the pyrolysis reactor will be studied by measuring the energy consumption used during the pyrolysis process by measuring the amount of LPG energy consumed during pre-heating process on reactor. The results of the temperature distribution profile in the reactor which is set manually using a regulator valve will be compared with those after using automatic temperature control. Fuel Consumption Rate (FCR) is determined by the equation:

$$FCR = \frac{mass\ of\ plastic - mass\ of\ char}{pyrolysis\ period}\ \left({}^{gram}/_{min}\right) \quad (2)$$

3. Result and Discussion

3.1 Temperature Distributions

Temperature distribution in the pyrolysis reactor is carried out by recording data from the thermocouple sensor input to the digital display and recorded every interval 2 minute. Automatic control to regulate temperature uses the Omron E5CC-RX2ASM-800 device to control the open-close operating of the solenoid valve to flow gas from the LPG heat source. Figure 3a shows the automatic temperature setting control circuit which consists of a solenoid valve at the inlet gas input section, leading to two valves to the heating furnace and a valve for the pilot jet. This solenoid valve is controlled via Omron digital temperature and is assembled in a panel box (Figure 3b).

(a) (b)

Figure 3. (a) Selenoid Digital Temperature, (b) Panel Box Control

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The performance of automatic temperature control was studied by comparing temperature distribution records at an operating temperature setting of 300 °C. Figure 4 shows the temperature distribution during the pyrolysis process before installing the heat cover and automatic temperature control. The significant fluctuations in temperature increase during the initial heating process in the reactor before installing the automatic temperature control sensor. The operating temperature of 300 °C was reached after 40 minutes and the temperature difference from the three sensors showed a relatively large value of 50 °C. This happens because during the reactor heating process, the gas flow valve from the LPG heat source is adjusted manually and based on the temperature reading, causing the interval valve to open and close inconstantly. The temperature difference of the three thermocouples shows significant results between the top and bottom temperatures of the reactor. This is due to heat transfer in the volume fraction of plastic waste during the pyrolysis process [18].

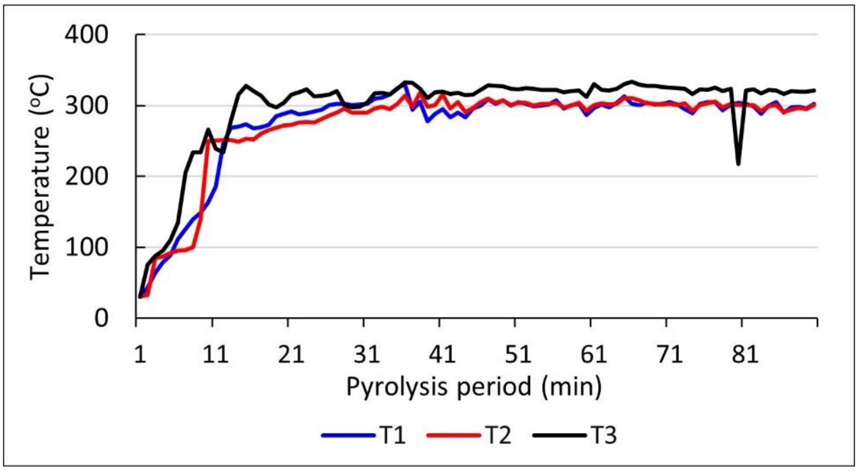

Figure 4. Temperature Distribution without Heat Cover

Figure 5 shows the temperature distribution in the pyrolysis reactor with the addition of temperature control and installation of a heat cover. The results show that the temperature increase from the beginning of the heating process continues until it reaches the operating temperature of 300 °C, the temperature distribution becomes more uniform and the time to reach the operating temperature becomes shorter at 33 minutes. The operating temperature up to the 90th minute shows that the temperature difference is not too significant at the three measurement points. This is influenced by the glasswool heat insulator is able to hold the heat and spreads horizontally towards the environment which shows good agreement with previous research [13]. Automatic temperature control with of 2 °C difference in thermos control makes it easy to control the temperature stability of the reactor with a constant on-off duration which results in a maximum difference of 20 °C at the three measurement points.

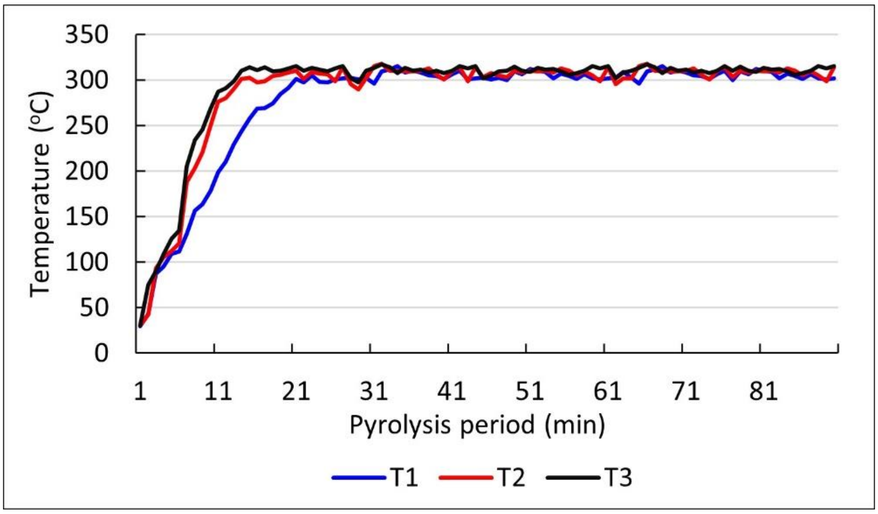

Figure 5. Temperature Distribution with Heat Cover

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3.2 Heating Energy Consumption

Table 1 showed that the amount of energy consumed increases along with increasing the pyrolysis heating setting temperature. This shows that the higher the reactor temperature, the greater the energy required for the pre-heating process from an external energy from LPG heat source until the set operating temperature is reached. The results of this research show suitability with lower energy consumption compared to the results of previous research, with energy consumption from LPG of 6 kg to reach a pyrolysis temperature of 300 °C which is equivalent to 5,6391.96 kcal [19].

Table 1. Heating Energy Consumption from Different Temperature

No	Temperature (°C)	LPG Consumption (kg)	Heating Energy (kcal)
1	250	2	22509
2	275	2,2	24760
3	300	2,5	28137

3.3 Fuel Consumption Rate

The fuel consumption rate (FCR) of LDPE plastic waste into fuel Figure 6 shows that the FCR increases as the pyrolysis reactor temperature increases. It is easy to understand as the higher the temperature so the rate of the fuel conversion into liquid/gas is more rapid. The results of this research are in good agreement with previous research using PP type plastic in a pyrolysis reactor [5].

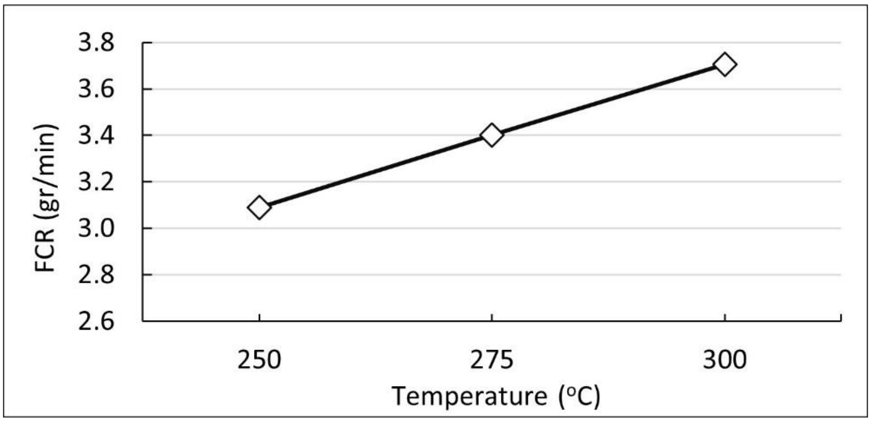

Figure 6. Fuel Consumption Rate from Different Temperature

4. Conclusion

The addition of a heat cover to the pyrolysis reactor shows that the temperature distribution in the reactor becomes more uniform at each measurement point to minimize heating treatment errors in the pyrolysis fuel. The addition of automatic temperature control makes operation easier with a deviation value of 2 °C indicating a maximum temperature difference between the three measurement points of 20 °C compared by previously done manually gives fluctuating results with a temperature difference of up to 50 °C. This makes it easier to operate and control temperature during the pyrolysis process. The experimental results of variations in pyrolysis temperature show that increasing the pyrolysis operating temperature affected the increase pre-heating energy. The fuel consumption rate (FCR) of pyrolyzed plastic waste shows an increase because the rate of the fuel conversion into liquid/gas is more rapid at higher operating temperatures.

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