Performance of Water-Cooled Spiral Type Condenser in A Plastic Waste Pyrolysis

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Abstract. Pyrolysis is a promising alternative for managing the substantial amount of low-density polyethylene (LDPE) plastic waste, particularly plastic bags. The high temperatures in the pyrolysis reactor can vaporize the plastic, necessitating a condensation process to capture this vapor as a liquid. The condenser design is crucial for maximizing this process and preventing the release of polluting oil vapor. Fized bed pyrolysis reactor with a capacity of 0.8 kg of plastic waste equipped with a water-cooled condenser made of copper pipe with a diameter of 3/8 inches and an overall length of 2000 mm. The copper pipe with a thermal conductivity of 386 W/m.K is formed in a spiral model with a coil diameter of 14 cm and a total of 10 coils. This study experimentally compared the performance of a water-cooled condenser in counter and parallel-flow configurations. The pyrolysis temperature operated at 300°C with a constant water flow rate of 3 liters per minute. The results indicated that a counter-flow condenser produced a higher volume of condensate (765 ml) compared to a parallel-flow condenser (680 ml). The counter-flow design was more effective in reducing non-condensable gases and mitigating the risk of environmental pollution.

Keywords: Flow Direction, LDPE Plastic, Pyrolysis, Water Cooled Condenser

1 Introduction

One type of plastic waste that is very easy to find is Low-Density Polyethylene (LDPE). The main characteristics are that it is easy to process, easy to shape using heat, and is formed from petroleum-based materials. Currently, various product discoveries using plastic materials have resulted in large amounts of waste being thrown into the environment. The pyrolysis process produces gas (H_2, CO, CO_2, H_2O, CH_4), tar, and charcoal from decomposition with a heating process without oxygen. The main product of pyrolysis is liquid oil which can be used as a fuel mixture or additive (Surono, 2018). In this preliminary study, a pyrolysis test setup was designed. Plastic waste was placed inside a heated reactor tube. The heating elements were controlled by a thermostat to melt and decompose the plastic into smaller hydrocarbon compounds. The resulting gaseous products were then passed through a cooling tube. The cooled oil was collected in a storage vessel (Rahtika, 2019). The production of gas yield and liquid fraction

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composition will be affected by the temperature during reactor heating. The composition of liquid fractions generally contains more aliphatic compounds at lower temperatures and aromatic compounds at higher temperatures (Ghodke, 2021). The design and fabrication of household-scale fixed bed pyrolysis using LDPE plastic waste at operating temperature variations of 250, 275, and 300°C showed that the highest liquid fraction, color clarity level, and calorific value were produced at the highest temperature of 300°C (Putrawan, 2022). Another effort was made by optimizing the temperature in the pyrolysis reactor using a heat cover to reduce the rate of heat loss which is integrated with an automatic heating control system. The results showed that automatic heat control and the installation of a heat cover were able to reduce temperature fluctuations during the pyrolysis process (Putrawan et al, 2024).

In the pyrolysis reactor, the condenser's role in the steam condensation process becomes very important because the heating process is high (up to 700–800°C). The conductivity of the condenser material has a major influence on the effectiveness of the heat transfer process that occurs, the higher the conductivity value of the material, heat transfer process becomes more efficient. Research on optimizing cooling through pyrolysis condenser design has been conducted by (Batutah et al., 2021), which involves designing a spiral flow condenser with a pipe length of 3000mm and a diameter of 30 cm made of ½ inch galvanized iron, capable of producing 100 ml of condensate from 1000 grams of processed plastic waste. Other research has varied the length of the copper condenser pipe to process 1000 grams of plastic waste for 60 minutes. The results showed that the highest oil volume was obtained at a length of 2000 mm, which is 400 ml, compared to a length of 1000 mm which produced 77.3 mm (Arisandi et al, 2020). Other research involved adding ice cubes as a cooling medium in a spiral-type condenser conducted by (Putra et al., 2022). The research results showed that the pyrolysis oil yield from 1000 grams of plastic waste was 340 ml using ice cubes compared to water cooling which produced 130 ml of condensate.

Several studies have been conducted to improve the efficiency of pyrolysis systems in plastic waste processing. A suboptimal condenser can lead to the incomplete condensation of the liquid smoke produced during the pyrolysis process, resulting in its release into the atmosphere and causing environmental pollution. To ensure the most efficient condensation process, the condenser needs to be optimized using a water-cooled shell and tube design. This research investigates the performance of plastic waste pyrolysis using a water-cooled shell and tube condenser with different flow direction variations (counter and parallel flow).

2 Methodology

2.1 Reactor Pyrolysis

The 0.01 m^3 household scale batch reactor pyrolysis was constructed of stainless steel with dimensions of 260 mm in diameter and 250 mm in height. The feeder at the top of the reactors is used to feed LDPE plastic into the reactor. To prevent gas leaks, the feeder valve is securely closed. An LPG fuel source is used for the pyrolysis reactor's initial heating. Omron E5CC-RX2ASM-800, which is linked to a solenoid valve to control the gas flow valve system (open and close) operates automatically.

To reduce heat loss in the reactor, a heat cover made of heat-resistant material from a combination of glass wool and jute. A glass wool with a thickness of 25 mm is applied as the first layer to the reactor to prevent heat loss (Firdaus et al., 2023). Furthermore, jute as the second layer with a thickness of 5 mm is used because it is an environmentally benign natural material.

Figure 1. Fixed bed reactor pyrolysis

2.2 Condenser Design

The design of the spiral-type shell and tube condenser uses a 3/8 inch copper pipe with a diameter of 9.52mm and a thickness of 0.6mm. The selection of copper material by considering the thermal conductivity of copper material is 386 W/m.K. The condenser pipe fabrication process uses a bending process with a total length of copper pipe of 2000 mm. The diameter of the condenser coil is 14 cm with the number of turn coils is 10 turns.

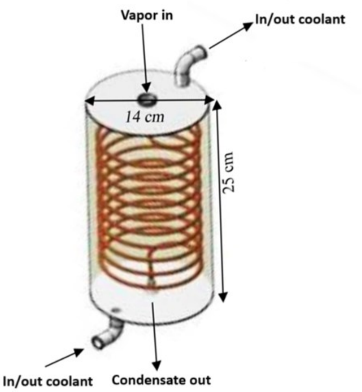

Figure 2. Spiral type shell and tube condenser

2.3 Experimental Setup

Up to 0.8 kg of pre-treated and processed LDPE plastic waste (soil residue, water, and metal materials) are fed into the reactor via the feeder. To initiate preheating, the operating temperature was adjusted to 300ºC. Three thermocouples—placed at the bottom, middle, and top of the reactor—that are real-time connected to the temperature display are used to measure the temperature distribution profile within the pyrolysis reactor. Through the top of the condenser, hot gas exiting the pyrolysis reactor enters the pipe tube, condenses, and then falls naturally. The water coolant is circulated on the outside (shell) using a circulation pump with a constant flow rate of 3 liters per minute (Lpm). The direction of the condenser cooling water in the counter and parallel flow is done by swapping the inlet and outlet sides of the cooling flow. The performance of the pyrolysis process is represented by the weight of the ash or residue and the volume of condensate oil produced. The weight of pyrolysis oil produced using the equation:

$$Yield\ product\ (kg) = Density\left(\frac{kg}{m^3}\right).volume\ (m^3) \quad (1)$$

3 Result and Discussion

3.1 Temperature Distribution

The temperature distribution in the pyrolysis reactor is depicted in Figure 3. The temperature rises steadily from the start of the heating process until it reaches the operating temperature of 300°C, the temperature distribution becomes uniform, and it takes 33 minutes to achieve the operating temperature. The operational temperature until the 90 minutes indicates that the three measurement point temperature differences are not very noticeable. This is affected by the glass wool heat insulator, which exhibits good agreement with earlier studies (Prasetyo & Siregar, 2013)

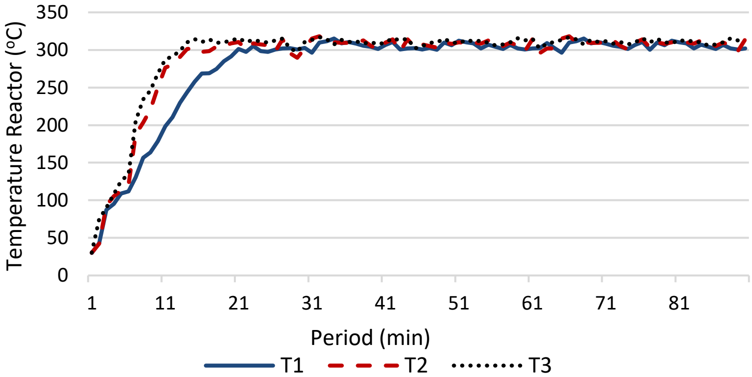

Figure 3. Temperature reactor distribution

3.2 Pyrolysis Product

According to the results of the study conducted on 1 kg of waste LDPE plastic during the pyrolysis process using a water-cooled condenser the volume of condensate was 765 ml in the counter flow. This outcome is in line with earlier studies (Alit et al, 2022). Condensate volume was observed to have decreased by 684 ml in the parallel flow type. High heat absorption in counterflow results in a quick drop in temperature in pyrolysis gas, which directly impacts the increase in condensate oil production. In parallel flow, heat exchange between fluids on the inside wall of the condenser pipe and gas and the pipe wall on the outside of the condenser are ineffective because the fluids move in the same direction, which lowers the heat transfer rate's capacity (Suyitno et al., 2021).

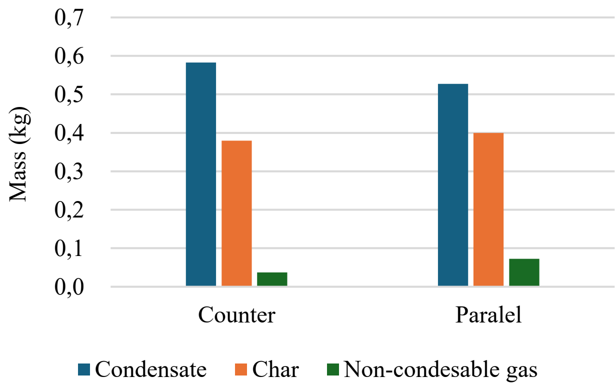

Figure 4. Pyrolysis product

Figure 4. shows the pyrolysis products based on the mass fraction measured in the mass of condensate and mass of char/residue. Condensate mass refers to the amount of volume produced multiplied by the oil density of 771 kg/m^3 (Papari et al, 2021).The mass of non-condesable gas is calculated using the mass of plastic inserted, which is 0.8 kg - mass of condensate - mass of char/residue. The amount of non-condensable gas during the pyrolysis process is 0.04 kg in the counter flow and 0.091 kg in the parallel flow. This shows that the type of counter flow can limit the amount of smoke released, lowering the danger of pollution to the environment. After the reactor's residual char and residue are weighed, it is discovered that the counter flow model gains 0.38 kg of char and residue, increasing the parallel flow by 0.40 kg.

4 Conclusion

The results of the study showed that the addition of a heat cover was able to isolate the heat coming out in the horizontal direction so that the temperature distribution profile in the reactor became more uniform. The type of counter flow cooling in the condenser showed better pyrolysis product results compared to the parallel flow type. The counter flow type is able to reduce the amount of non-condesable gas and can reduce the danger of ambient air pollution.

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