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Experimental Validation of the Performance of a Mini-Scale Plastic Waste Pyrolysis Reactor with a Waste Oil Burner Heating System

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Abstract— *The accumulation of plastic waste is an environmental problem that requires effective and sustainable processing technology. One method that can be applied is pyrolysis, the thermal decomposition of plastic in the absence of oxygen, producing pyrolysis oil, gas, and solid residue. This study aims to validate the performance of a mini-scale plastic waste pyrolysis machine using a used oil burner heating system through experimental testing and to compare the results with heat transfer theory and machine performance parameters.The research method used was an experimental method using polypropylene (PP) and polyethylene terephthalate (PET) plastic as raw materials. Tests were conducted using 2 kg of plastic, with a reactor operating temperature of 325°C, and a processing time of 60 minutes. Observed parameters included reactor temperature, heat transfer, fuel consumption, pyrolysis oil volume, and solid residue mass.The results showed that the pyrolysis machine operated satisfactorily using a used oil burner as a heat source. The pyrolysis process produced 165 mL of pyrolysis oil, with a solid residue mass of 0.30 kg, and used oil fuel consumption of 600 mL. Heat transfer analysis indicates that conduction, convection, and radiation mechanisms play a role in heating the reactor to the required operating temperature. Validation results indicate that the mini-scale pyrolysis machine is capable of converting plastic waste into liquid fuel using a simple, economical heating system, and has the potential to be implemented as an alternative for small-scale plastic waste processing.*

Keywords— *Pyrolysis, Plastic Waste, Used Oil Burner, Experimental Validation, Pyrolysis Oil.*

I. Introduction

The problem of plastic waste is becoming an increasingly serious environmental issue worldwide, including in Indonesia. Plastic is a material that decomposes slowly in the environment, taking hundreds of years to break down organically. The accumulation of plastic waste in landfills not only disrupts the aesthetics and cleanliness of the environment but also negatively impacts the soil, water, and living things. Therefore, innovative efforts are needed to process plastic waste into useful and environmentally friendly products.

One potential technology to address this problem is pyrolysis, the thermal decomposition of organic matter at high temperatures in the absence of oxygen. Through this process, plastic waste can be converted into liquid fuel (pyrolysis oil), gas, and solid residue. The pyrolysis oil has characteristics similar to conventional fuel oil, making it potentially useful as an alternative energy source.

In addition to the heating system, a simple condensation system also plays a crucial role in determining the volume and quality of the pyrolysis oil produced. This system functions to efficiently convert the vapor from pyrolysis into liquid form at a low production cost. To ensure that the machine design performs as expected, experimental validation of the pyrolysis machine's performance was conducted.

This validation allows for the accuracy of the experimental results compared to the theory or design calculations. The research findings are expected to contribute to the development of efficient, affordable, and environmentally friendly small-scale plastic waste processing technology, as well as a concrete step in supporting sustainable waste management in Indonesia.

II. Research Methodology

A. Research Procedure

A research flow framework is a systematic process implemented from the beginning to the end of a research activity. This flow encompasses all processes involved in conducting the research. The research flow framework and complete research procedures are presented in Figure 1.

B. Measurement

Measurement is a crucial step in experimental research because it serves to obtain accurate data on the operating conditions of the pyrolysis machine during the process. All parameters are measured using measuring instruments tailored to the research needs, allowing the data to serve as a basis for analyzing machine performance. Observed parameters include reactor temperature, heating time, and temperature measurement points at various parts of the machine.

Based on Table 1, the reactor temperature was measured periodically using a thermocouple or infrared thermometer throughout the pyrolysis process. Heating time was recorded using a stopwatch from the time the burner was turned on until the pyrolysis process was completed. All these measurements serve as primary data for determining heat transfer characteristics, heating system efficiency, and the success of the pyrolysis process.

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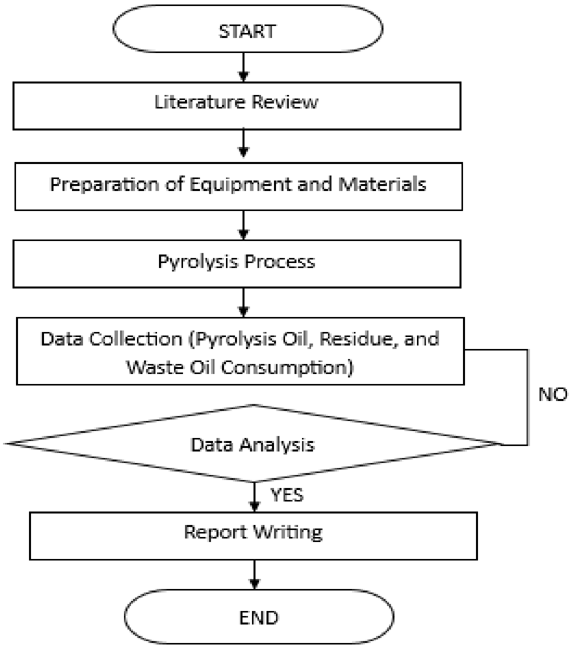

Fig. 1. Research Flowchart

TABLE I. Measurement

No	Parameter	Measuring instrument	Information
1	Reactor temperature	Thermocouple / IR thermometer	Recorded at each time interval
2	Warm-up time	Stopwatch	Since the burner was turned on
3	Measurement point	Reactor walls	Reactor center point

C. Data Logging

In addition to direct measurements, this study also recorded the main parameters of the pyrolysis process. The recorded data was used as a reference in analyzing the performance of the mini-scale pyrolysis machine. Each parameter was selected based on its impact on pyrolysis oil yield and process efficiency.

TABLE 2. Data Logging.

No	Parameter	Information
1	Types of plastic	PE, PP
2	Plastic mass	1–2 kg
3	Pyrolysis temperature	300–500 °C
4	Testing time	±60 minutes

The data in Table 2 shows the basic parameters used during the experiment, including plastic type, raw material mass, operating temperature, and pyrolysis duration. All parameters were kept constant to allow for a more objective analysis of the variables' influence on pyrolysis results. The obtained data were then used in the experimental validation process and pyrolysis machine performance calculations.

D. Tools and materials

The tools used in this research were a mini-scale pyrolysis reactor to heat plastic materials without oxygen to produce new products such as pyrolysis oil. A used oil burner was used to heat the reactor and ignite the flame. This oil burner uses used oil as fuel, processed through a steam pressure system to produce more efficient and clean combustion. A blower was used to control and increase air flow into the combustion chamber, resulting in a more complete combustion process, fuel efficiency, and reduced black smoke and odor during combustion. Condensation was used to convert gas into liquid by cooling the hot gas exiting the reactor, thus producing oil. The research objective was the performance of a mini-scale plastic waste pyrolysis machine with a used oil burner heating system.

The research focused on testing the device's ability to process plastic waste into pyrolysis oil by analyzing process parameters such as reactor temperature, pyrolysis time, burner fuel consumption, volume of pyrolysis oil produced, and the amount of residue formed. These test results were used to evaluate the effectiveness and performance of the designed pyrolysis machine

E. Research Procedure

This research procedure was conducted using an experimental method to validate the performance of a mini-scale plastic waste pyrolysis machine using a used oil burner heating system. All research stages were carried out systematically, from equipment and material preparation, through the pyrolysis process, data collection, and analysis of test results. The research stages were structured to ensure the data obtained was accurate and could be used to evaluate the performance of the pyrolysis machine. Furthermore, the research was conducted sequentially to ensure that all data obtained was valid, scientifically accountable, and able to reflect the actual performance of the mini-scale plastic waste pyrolysis machine being tested.

III. Analysis and Discussion

A. Pyrolysis Machine Performance

The performance of the pyrolysis machine was analyzed to determine the machine's ability to convert plastic waste into pyrolysis oil using a used oil burner heating system. Experimental testing was conducted using 2 kg of Polypropylene (PP) and Polyethylene Terephthalate (PET) plastic as raw materials.

Fig. 2. pyrolysis process

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During the process, the main parameters observed included reactor temperature, process time, burner fuel consumption, volume of pyrolysis oil produced, and the mass of solid residue as shown in Fig 2.

B. Pyrolysis Machine Test Results

Pyrolysis Temperature Testing

The results of the reactor temperature test indicate the effect of operating time on temperature distribution within the system. The highest temperature during the test occurred at point T0, the location closest to the heat source. At 10 minutes, the T0 temperature was recorded at 153°C and increased significantly, reaching a maximum value of 346°C at 40 minutes. After 40 minutes, the T0 temperature tended to stabilize at around 325°C until the 60th minute, indicating that the reactor system was beginning to reach near-steady-state conditions, as shown in Table 3.

TABLE 3. Pyrolysis Temperature Testing

No	Time (minutes)	T_0	T_1	T_2	T_3	T_4
1	10	153°C	41°C	36°C	33°C	30°C
2	20	222°C	44°C	41°C	38°C	31°C
3	30	276°C	75°C	42°C	40°C	33°C
4	40	346°C	101°C	50°C	64°C	36°C
5	50	325°C	130°C	70°C	68°C	35°C
6	60	325°C	123°C	54°C	60°C	35°C

Manual Testing

➢ Conduction Calculation Q

$$= -kA.\Delta T/\Delta x$$

Where:
Q = Heat Flow Rate (Watts, W)
k = Thermal Conductivity of Material k = 45 W/m³
A = Cross-Sectional Area Heat Conduction Area = 0.25 m²
ΔT = Temperature difference between 2 points ΔT = T0 – T1 = 350℃ - 325℃ = 25℃
Δx = reactor thickness, heat transfer temperature L = 5 mm = 0.005 m
Calculation Steps:

$$Q = 45 \cdot 0{,}25 \cdot \frac{25}{0{,}005}$$

$$Q = 281 \cdot \frac{25}{0{,}005}$$

$$Q = 56.250\,W$$

The calculated heat transfer rate through the reactor wall by conduction is approximately 56.25 kW.

➢Convection Calculation

Q = h . A . ΔT
Note:
Q = convection heat propagation rate (W)
h = natural air convection coefficient, h = 15W/m°C
A = heat transfer cross-sectional area (m²), A = 40
ΔT = T1 - T2 = 325°C - 30°C = 295°C
Calculation:

$$Q = h \times A \times \Delta T$$

Q = 15 × 40 × (325 - 30)
Q = 15 × 40 × 295
Q = 2,212.5W
Conversion: Q = 2.21 kW
The heat released from the reactor surface to the surrounding air due to convection is 2.21 kW.

Energy Calculation

The heating energy of the plastic is calculated using the heat equation.

$$Q = m \times c \times \Delta T$$

Where:
Q = heat energy (J) ṁ = Plastic Mass (kg)
C = Plastic Specific Heat (J/kg°C)
ΔT = Temperature Change (°C)
Assuming:
Plastic Mass (ṁ) = 2 kg
Plastic Specific Heat Capacity (C) = 2 kJ/kg·°C
Temperature Change (ΔT) = 325 − 30 = 295 °C
Calculation:
Q = 2 × 2 × 295 = 1180 kJ = 1.18 M
Calculation using software

➢ Heat Transfer by Conduction

$$Q = -kA.\Delta T/\Delta x$$

Where:
Q = Heat Flow Rate (Watts, W) k = Material Thermal Conductivity k = 45 W/m·℃
A = Cross-sectional area. Heat-controlled area = 0.25 m^2
ΔT = Temperature difference between 2 points. ΔT = T0 – T1 = 500℃ - 447℃ = 53℃
Δx = Reactor thickness, heat transfer temperature. L = 5 mm = 0.005 m
Calculation Steps:

$$Q = 45 \cdot 0{,}25 \cdot \frac{53}{0{,}005}$$

$$Q = 281 \cdot \frac{53}{0{,}005}$$

$$Q = 119{,}250\,W$$

The calculated heat transfer rate through the reactor wall by conduction is approximately Q = 11925 kW

Using the Convection Formula (Newton's Law)

$$Q = h \cdot A \cdot \Delta T$$

Q = convection heat propagation rate (W) h = natural air convection coefficient, h = 15 W/m²°C
A = heat transfer cross-sectional area (m²), A = 40
ΔT = T1-T2 = 500°C - 447°C
Calculation:

$$Q = h \times A \times \Delta T$$

Q = 15 × 40 × (500 - 447)
Q = 15 × 40 × 53
Q = 31,800 W
Q = 31.8 kW
The heat released from the reactor surface to the surrounding air due to convection is 31.8 kW

➢ Energy Estimation Calculation

$$Q = m \times c \times \Delta T$$

Description: Q = heat energy (J) ṁ = Plastic Mass (kg)
C = Plastic Specific Heat Capacity (J/kg°C)
ΔT = Temperature Change (°C)
Assuming:
Plastic Mass = 2 kg

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Specific Heat Capacity plastic = 2 kJ/kg·°C
Temperature change (ΔT) = 500 - 447 = 53 °C
Calculation:
Q = 2 × 2 × 53 = 212 kJ = 0.212 M

C. Data processing results

➢ Temperature Decrease 222°C

Temperature changes during the pyrolysis process, with an initial reactor bottom temperature of 222°C. At the beginning of the process (T0), the temperature recorded is the highest, at around 325°C. This indicates that in the initial stage, the reactor still stores a large amount of heat energy to initiate the pyrolysis process. Figure 3

Fig. 3. Temperature Decrease 222°C

➢ Temperature Decrease at 276°C

The temperature at the bottom of the reactor decreased at each point in the pyrolysis process, from T0 to T4, with a total decrease of 276°C. At T0, the temperature remained very high, around 325°C. As the process progressed to T1, the temperature dropped quite drastically to around 123°C, indicating rapid cooling in the initial stages. This is shown in Figure 4.

Fig. 4. Temperature Decrease at 276°C

➢ Temperature Decrease at 346°C

The temperature at the bottom of the reactor decreased at each pyrolysis point, from T0 to T4, with an initial temperature of 346°C. At T0, the temperature was still very high, around 325°C. As the pyrolysis process began, the temperature dropped quite drastically at T1, reaching around 120°C. Figure 5

At point T2, the temperature drops again to around 70°C, indicating that the heat inside the reactor continues to decrease as the process progresses. At point T3, the temperature tends to stabilize at around 68°C, indicating that the temperature drop is starting to slow and conditions inside the reactor are becoming more stable. Table 4 Temperature Decrease

Fig. 5. Temperature Decrease at 346°C

TABLE 4. Temperature Decrease

No	Time (minutes)	Temperature	T_0	T_1	T_2	T_3
1	10	222°C	153°C	41°C	36°C	33°C
2	20	272°C	222°C	44°C	41°C	38°C
3	30	346°C	276°C	75°C	42°C	40°C

D. Comparison of Experimental and Simulation Graphs

➢ Comparison of Graphs at 222°C

Based on Graph 1, Comparison of Graphs at 222°C, it can be seen that the initial temperature at point T0 is the same, namely 222°C, but the temperature decrease patterns are different. The first graph (in blue) shows an uneven temperature decrease with a sharp drop at T2, while the second graph shows a more stable and gradual temperature decrease at each pyrolysis point. This indicates that the heat distribution in the second graph is more even than in the first

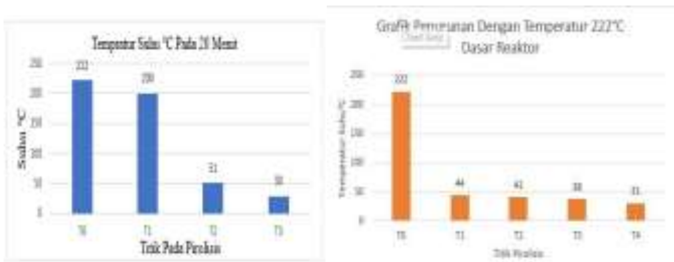

Fig. 6. Comparison of Graphs at 222°C

➢ Temperature Comparison Graph at 276°C

Based on Graph 2, the first graph (blue) shows the temperature distribution after 30 minutes of pyrolysis, with T0 at 276°C, decreasing to 248°C at T1, then dropping drastically at T2 (57°C) and T3 (30°C), indicating a decrease in heat intensity with distance from the heat source.

The second graph (orange) shows the temperature decrease until T4, starting at 276°C at T0, dropping sharply at T1 (75°C), then gradually decreasing at T2 (42°C), T3 (40°C), and T4 (33°C), indicating a more even heat distribution despite the lower final temperature.

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Comparing the two graphs shows a consistent downward trend from T0 to the next point. The first graph shows a higher temperature at T1, while the second graph shows a more gradual decrease to the furthest point, indicating differences in conditions or measurement duration that affect heat distribution in the pyrolysis process.

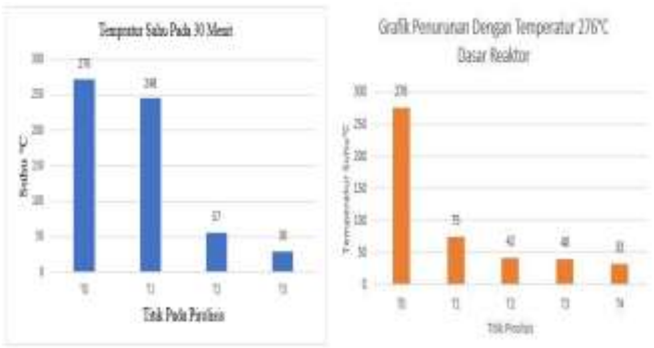

Fig. 7. Temperature Comparison Graph at 276°C

➢ Temperature Comparison Graph at 346°C

Based on Graph 2, Temperature Comparison at 346°C, the first graph (blue) shows a very sharp temperature drop, especially from T1 to T2, indicating uneven heat distribution and rapid heat loss. In contrast, the second graph (orange) shows a more gradual temperature drop with small fluctuations, resulting in a more stable heat distribution. Furthermore, the second graph has more measurement points (T0–T4) than the first graph (T0–T3), providing a more detailed picture of the temperature distribution along the pyrolysis pathway.

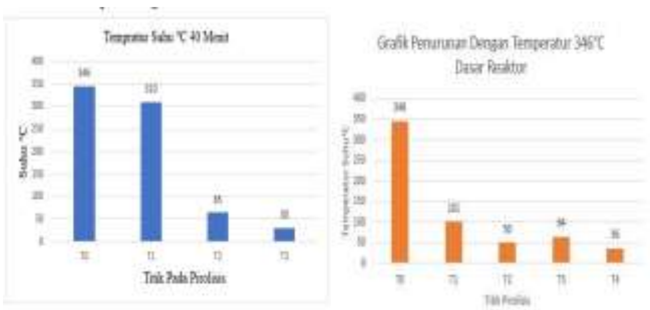

Fig 8. Temperature Comparison Graph at 346°C

IV. CONCLUSION

Based on the results of research, experimental testing, and performance analysis of a mini-scale plastic waste pyrolysis machine with a used oil burner heating system and a simple condensation system, the following conclusions can be drawn:

1. The mini-scale pyrolysis machine designed in this study operated well and in accordance with the pyrolysis principle, namely, it was able to convert mixed plastic waste of polypropylene (PP), polyethylene (PE), and polyethylene terephthalate (PET) into pyrolysis oil as a liquid product.
2. Test results showed that the reactor operating temperature, process time, and heating system stability significantly influenced the machine's performance, particularly in determining the rate of plastic decomposition and the amount of pyrolysis oil produced.
3. During the test, the reactor reached a maximum temperature of approximately 325°C within 60 minutes of heating, which is considered medium-temperature pyrolysis. Under these conditions, the plastic decomposition process could already occur, but it was not yet fully optimized to produce a higher oil yield.
4. The used oil-fueled heating system still exhibits unstable flames and fluctuating fuel supply, resulting in inconsistent heat generation. This results in low reactor heating efficiency and limits the achievement of higher operating temperatures.
5. A simple condensation system with a static water coolant is capable of converting pyrolysis vapor into oil, but its effectiveness decreases as the cooling water temperature increases. As a result, some vapor is not fully condensed, affecting the amount of oil collected.
6. Comparison of simulation and experimental results shows that the temperature distribution and reduction patterns tend to be similar, although there are quantitative differences. These differences are primarily due to heat loss to the environment, combustion instability, and limitations of the insulation system under actual test conditions.
7. Overall, this study demonstrates that a mini-scale pyrolysis machine with a used oil burner heating system can be developed as a simple and relatively economical system. However, improvements are still needed, particularly in terms of heating stability, thermal efficiency, and condensation system performance to achieve optimal results.

V. RECOMMENDATIONS

Based on the research results and limitations identified during the testing process, several recommendations for further development are as follows:

1. Heating System Development
   It is recommended to use a more stable heating system, for example by adding automatic fuel and air flow control. Furthermore, further research could compare the use of other heat sources, such as LPG or electric heaters, to improve reactor temperature stability and efficiency.
2. Reactor Thermal Insulation Improvement
   It is necessary to improve the thermal insulation layer, both on the reactor walls and the pyrolysis gas ducts, to reduce heat loss to the environment, thus allowing the heating process to proceed more efficiently.
3. Condensation System Optimization
   It is recommended to use a condensation system with circulating cooling air or a multi-stage condenser system to more effectively condense the pyrolysis vapor into oil and increase the amount of oil produced.
4. Variation of Operating Parameters
   Further research is expected to vary operating

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temperature, process time, and plastic type and composition in more detail to find the most optimal operating conditions for producing pyrolysis oil of better quality and quantity.

5. Feasibility Study and Scale-Up

Further studies are needed on the economic aspects, energy efficiency, and potential for larger-scale machine development so that this technology can be practically implemented, both at the community level and on a small-scale industry scale.

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