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Validation of Plastic Waste Pyrolysis Prototype Design Based on Used Oil Burner with A Simple Condensation System Using Software

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Abstract: Plastic waste is a serious environmental problem because it is difficult to decompose and its volume continues to increase. One potential solution is pyrolysis technology, a thermal decomposition process at high temperatures in the absence of oxygen that produces oil, gas, and solid residue. This study aims to validate the performance of simulation software in designing a prototype pyrolysis machine using a used oil burner with a simple condensation system through design, simulation, and experimental testing. A three-dimensional model was created using SolidWorks, while temperature distribution analysis was performed using ANSYS. The prototype was designed to process approximately 2 kg of PP and PET plastic at 300–500°C. Parameters analyzed included reactor temperature distribution, condenser temperature drop, and heating and cooling system performance. Both simulation and experimental results demonstrated good performance. The used oil burner produced stable heat, and the condensation system effectively converted steam to oil, demonstrating the prototype's potential for development into an efficient and economical small-scale pyrolysis machine.

Keyword: Plastic Pyrolysis, Used Oil Burner, Condensation System, SolidWorks, ANSYS, Prototype Validation.

INTRODUCTION

The problem of plastic waste is an increasingly pressing global environmental concern, including in Indonesia. Plastic is a material that is difficult to decompose naturally, taking hundreds of years to degrade. The accumulation of plastic waste in landfills not only damages the beauty and cleanliness of the environment but also negatively impacts the soil, air, and living things. Therefore, innovative approaches are needed to process plastic waste into useful and environmentally friendly products.

One promising technology to address this problem is pyrolysis, the thermal decomposition of organic matter at high temperatures in the absence of oxygen. This process allows plastic waste to be converted into pyrolysis oil, gas, and solid residue. The resulting pyrolysis oil has properties similar to conventional fuels, making it a potential alternative energy source.

Through validation of a pyrolysis prototype software based on a used oil burner with a simple condensation system, we can analyze the synchronization between simulation results, design calculations, and prototype performance with the theory used. The results of this research are expected to support the development of efficient, economical, and environmentally friendly small-scale plastic waste processing technology and become a concrete step towards sustainable plastic waste management in Indonesia.

METHOD

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 is as follows:

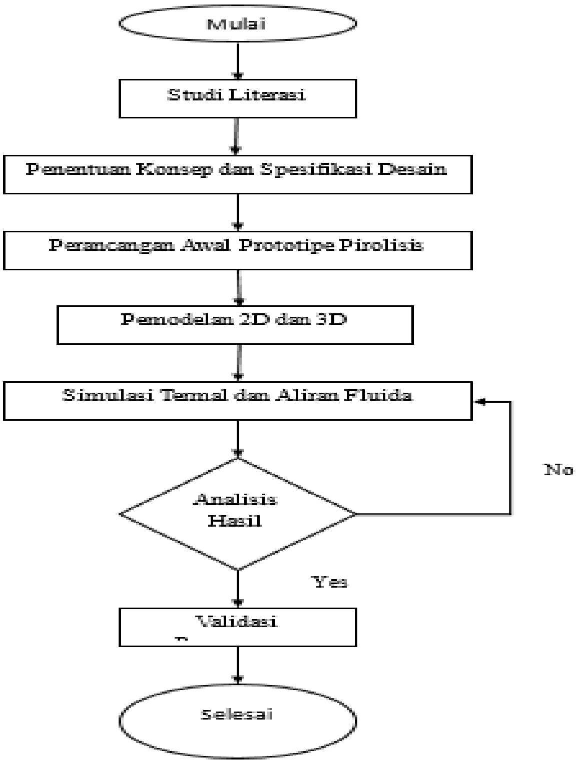

Figure 1. Research Flowchart

Tools and Materials

The tools used in this research are SolidWorks software to design and simulate three-dimensional (3D) prototypes, and ANSYS to perform thermal analysis and two-phase flow simulations (two-phase flow) on the system under study. SolidWorks is used to create geometric designs and component assembly, while ANSYS is used to analyze temperature distribution, heat transfer characteristics, and two-phase fluid interaction phenomena based on predetermined parameters. The research object is a system prototype that is explained through the modeling and simulation process.

Heat transfer can also occur through the movement of fluids, either gas or liquid. In a pyrolysis reactor, convection occurs when hot air or combustion gases from the burner reach the reactor surface, allowing heat to be distributed more evenly. Furthermore, convection also occurs in condensation systems when the cooling medium, water or air, absorbs heat from hydrocarbon vapor.

Research Procesure

The research stages were carried out according to the flow in Figure 1. The research process began with problem identification, followed by the design of a prototype model using SolidWorks. After the design was completed, simulations were conducted using ANSYS to analyze the thermal characteristics and two-phase flow of the system.

Next, the simulation results were evaluated, including temperature distribution, fluid flow patterns, and heat transfer. If the simulation results did not meet the specified parameters, design and simulation iterations were carried out until optimal results were achieved. Once the results were confirmed, the final design was finalized and the research was declared complete.

RESULT AND DISCUSSION

2D and 3D Design

Pyrolysis prototype modeling is a comprehensive design stage that represents all the main components of the pyrolysis system in a single, integrated model. This modeling includes the pyrolysis reactor, waste oil burner, oil tank, blower, steam delivery pipe, and condensation system. The modeling process is performed using design and simulation software to realistically depict the geometry, component relationships, and heat and fluid flow before the prototype is physically constructed. As shown in (Figure 2).

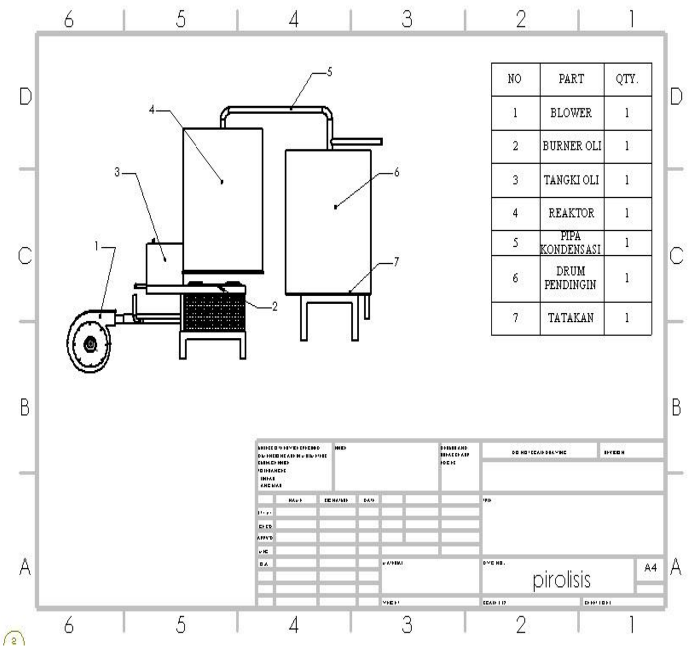

Figure 2. Pyrolysis Design

Thermal Simulation and 2-Phase Flow Using Ansys

A. Thermal Simulation

The results of the steady-state thermal simulation show a gradual temperature decrease from the pyrolysis reactor to the end of the condensation system. In the reactor (T0), the initial temperature was recorded at 500°C, marked in red, indicating the zone with the highest heat energy, which is the primary source of the pyrolysis process.

Next, at the beginning of the steam delivery pipe (T1), the temperature decreased to around 395°C. This decrease was caused by heat transfer through the pipe walls and heat loss to the surrounding environment.

In the condenser section (T2), the temperature dropped drastically to 82°C. This indicates that heat release is more intensive due to the length of the spiral pipe and the larger surface area for heat transfer.

At the end of the system (T3), the temperature reached a minimum of around 30°C, indicating that heat has been optimally dissipated and the condensation system is operating effectively. This temperature distribution illustrates the continuous and stable heat transfer from T0 to T3, in accordance with the principles of steady-state heat transfer. As shown in (Figure 3).

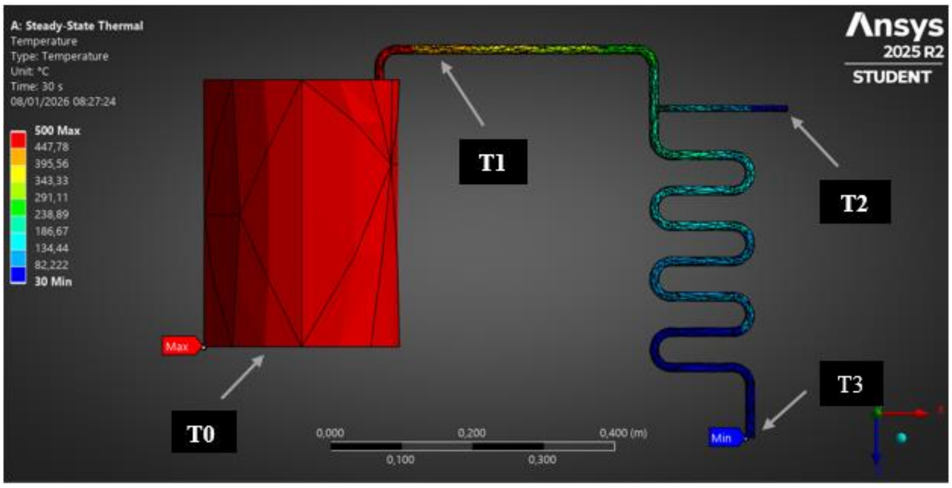

Figure 3 thermal simulation

Calculation using ansys

- Heat Transfer by Conduction

$$Q = -k.A.\frac{\Delta T}{\Delta x}$$

Where:
Q = Heat Flow Rate (Watts, W)
k = Thermal Conductivity of Material k = 45 W/m·°C
A = Cross-Sectional Area Area conducted by heat = 0.25 m^2
ΔT = Temperature difference between 2 points ΔT = T0 – T1 = 500°C - 447°C = 53°C
Δx = Thickness of the reactor, heat transfer temperature L = 5 mm = 0.005 m
Calculation Steps:

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

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

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

The result of the calculation of the rate of heat transfer 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

$\Delta T = T1 - T2 = 500°C - 447°C$
Calculation: $Q = h \times A \times \Delta T$
$Q = 15 \times 40 \times (500 - 447)$
$Q = 15 \times 40 \times 53$
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 = Mass of Plastic (kg)
C = Specific heat capacity of plastic (J/kg°C)
ΔT = Temperature change (°C)
Assuming:
Mass of plastic = 2 kg
Specific heat capacity of plastic = 2 kJ/kg·°C
Temperature change (ΔT) = 500 - 447 = 53 °C
Calculation:

$$Q = 2 \times 2 \times 53 = 212 \text{ kJ} = 0.212 \text{ M}$$

Experimental 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 Conducted Area = 0.25 m^2
ΔT = Temperature difference between 2 points $\Delta T = T0 – T1 = 350°C - 325°C = 25°C$
Δx = reactor thickness, heat transfer temperature L = 5 mm = 0.005 m
Calculation Steps:

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

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

$$Q = 56.250 \text{ W}$$

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

$$Q = h \,.\, A \,.\, \Delta T$$

Note:
Q = convection heat propagation rate (W)
h = natural air convection coefficient, h = 15 W/m°C
A = heat transfer cross-sectional area (m^2), A = 40
$\Delta T = T1 - T2 = 325°C - 30°C = 295°C$
Calculation:

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

$Q = 15 \times 40 \times (325 - 30)$
$Q = 15 \times 40 \times 295$

Q = 2,212.5W
Qconversion = 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)
$\dot{m}$ = Plastic Mass (kg)
C = Plastic Specific Heat (J/kg°C)
ΔT = Temperature Change (°C)
Assuming:
Plastic Mass ($\dot{m}$) = 2 kg
Specific heat capacity of plastic (C) = 2 kJ/kg·°C
Temperature change (ΔT) = 325 − 30 = 295 °C
Calculation:

$$Q = 2 \times 2 \times 295 = 1180 \text{ kJ} = 1.18 \text{ M}$$

B. Thermal Simulation

2-Phase Simulation At T1, the plastic material inside the reactor begins to heat up until it enters the initial stage of evaporation, marked by the appearance of a yellow color as an indication of the transition phase. Next, at T2, the evaporation process takes place more intensely, accompanied by a phase change from vapor to oil, which is seen from the color shift from yellow to blue due to the decrease in temperature. At T3, the blue color indicates the flow of cooling water which accelerates the condensation process, allowing the pyrolysis oil to exit at the end of the pipe. Throughout the spiral pipe, the flow remains dominated by the vapor phase, indicating that cooling and condensation take place gradually until the outlet point. As shown in (Figure 4).

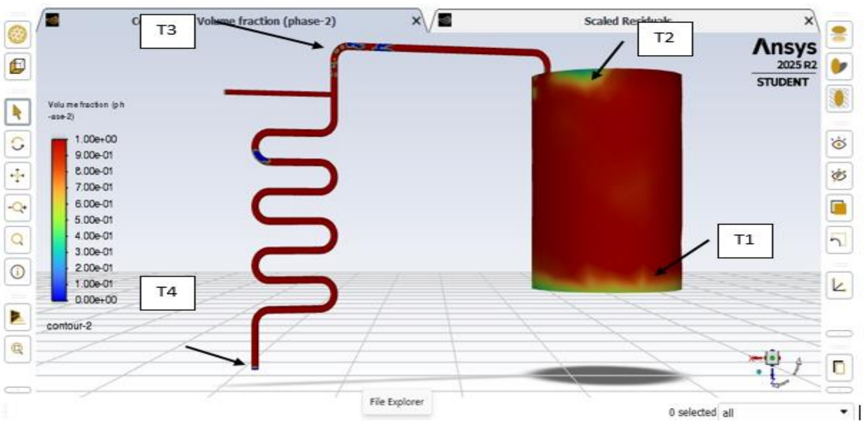

Figure 4 Two-phase simulation

Data Processing Results

- Temperature Decrease at 276°C

At an initial temperature of 222°C, the highest temperature was at point T0 (222°C), the reactor's heat source. The temperature then decreased to 200°C at T1, indicating heat transfer to the tube. A significant decrease occurred at T2 (51°C), indicating significant heat loss along the tube. At T3, the temperature reached 30°C, approaching ambient temperature and indicating effective cooling. (Figure 5)

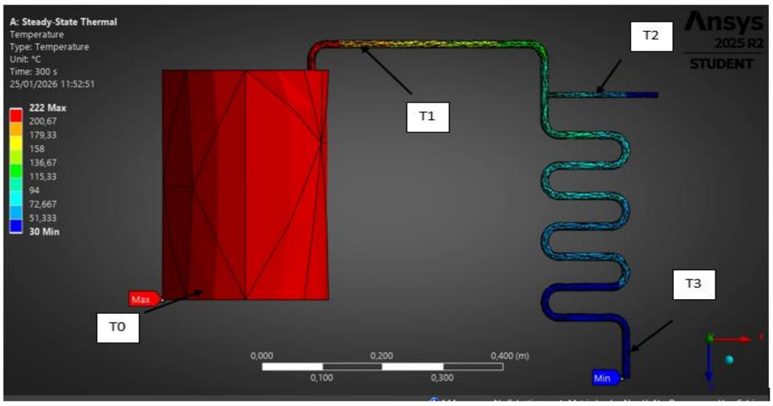

Figure 5 Temperature Drop at 276°C

- Temperature Decrease at 276°C

At an initial temperature of 276°C, the temperature at T0 was 276°C and dropped to 248°C at T1. A drastic decrease occurred at T2 (57°C), indicating significant heat dissipation. At T3, the temperature reached 30°C, indicating the condensation system was working optimally to reduce the temperature. This is shown in (Figure 6).

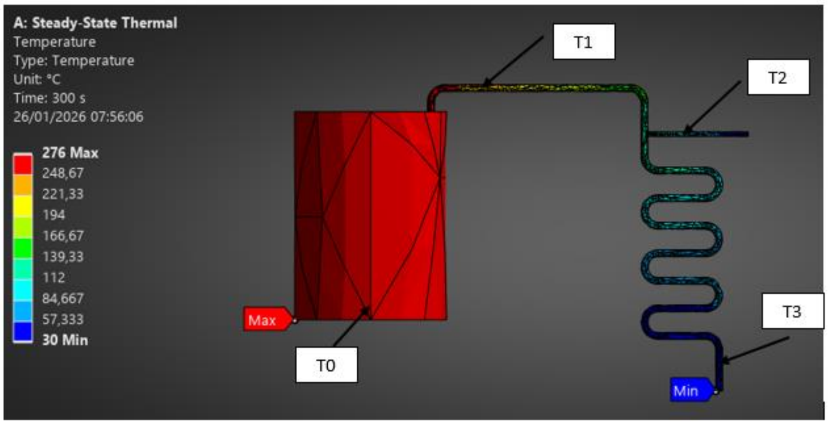

Figure 6 Temperature Decrease at 276°C

- Temperature Decrease at 346°C

At an initial temperature of 346°C, the highest temperature was recorded at point T0, which serves as the reactor's heat center. Subsequently, the temperature decreased to 310°C at point T1, indicating heat flow toward the supply pipe. A sharper decrease was observed at point T2, at 65°C, due to heat loss along the condensation pipe. At point T3, the temperature dropped to 30°C, or close to ambient temperature, indicating that the cooling system was functioning properly and effectively. (See Figure 7)

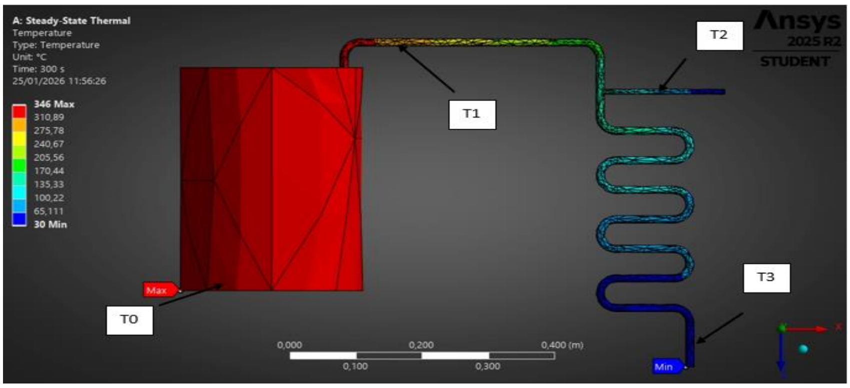

Figure 7 Temperature Decrease at 346°C

According to the table, the temperature increased with time from 20 to 50 minutes. At the 20th minute, the temperature at T0 was 222°C and gradually decreased until T3 reached 30°C. At the 40th minute, T0 rose to around 272–276°C, with a consistent temperature decrease from T1 to T3 of 30°C. At the 50th minute, the highest temperature was recorded at T0 at 346°C, then decreased at T1 (310°C), T2 (65°C), and stabilized at T3 (30°C). In general, the reactor temperature increased over time and the consistent temperature decrease from T0 to T3 indicated that the condensation system was operating effectively.

Table 1 Temperature Decrease

No	Time	temperature	T0	T1	T2	T3
1	20	222°C	222	200	51	30
2	40	272°C	276	248	57	30
3	50	346°C	346	310	65	30

Comparison of Simulation and Experimental 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.

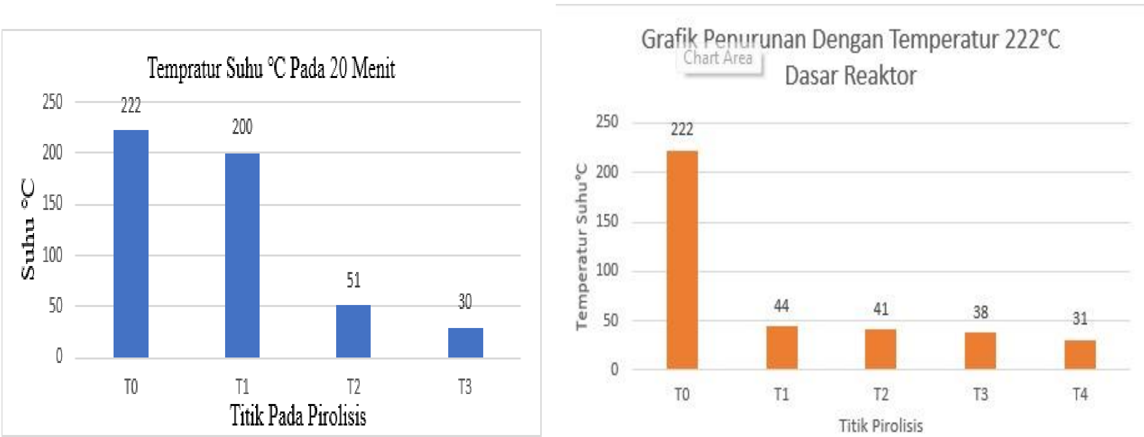

Figure 8 Comparison of Graphs at 222°C

- 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.

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.

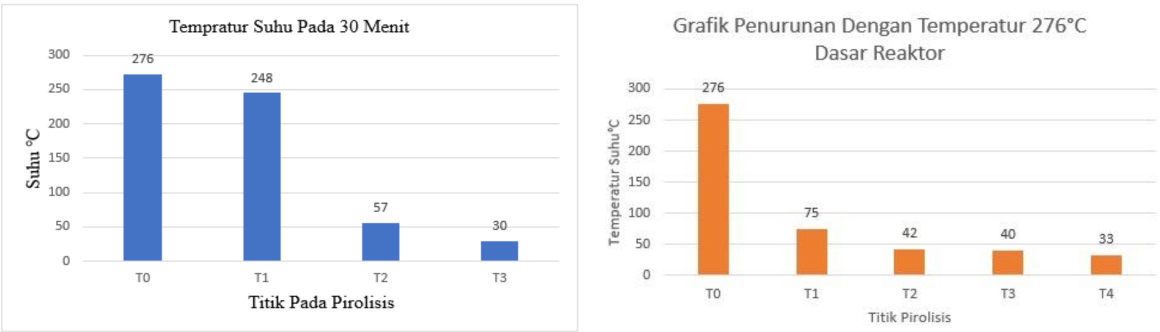

Figure 9 Temperature Comparison Graph at 276°C

- 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.

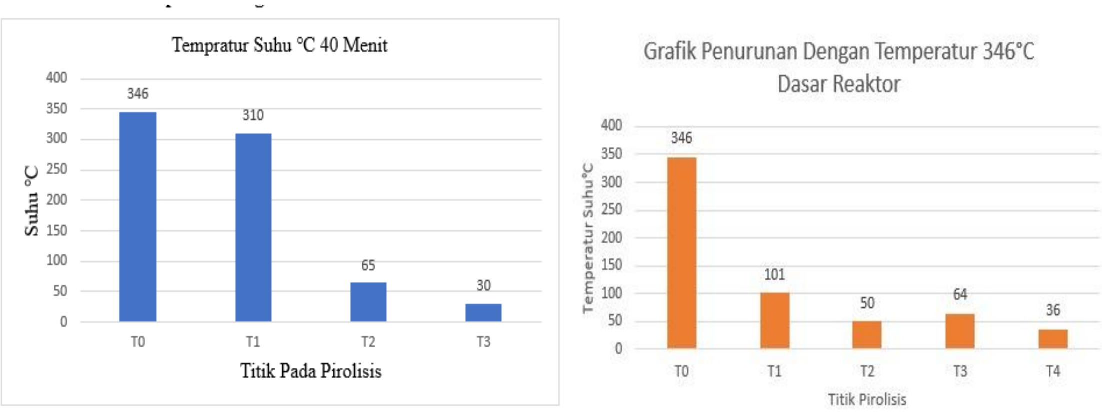

Figure 10 Temperature Comparison Graph at 346°C

Discussion

A comparison of the simulation and experimental results indicates differences in temperature and phase fraction values, but these are still within acceptable limits for a small-scale pyrolysis system. This difference is influenced by several factors, including variations in the combustion quality of the used oil burner, fluctuations in the combustion air supply, and environmental conditions during testing. Furthermore, limitations of the simple condensation system also affect the efficiency of vapor condensation into oil.

Overall, the comparison results indicate that the pyrolysis prototype design has been well validated. The temperature distribution pattern, phase change trends, and condensation system effectiveness in the simulation results are consistent with the experimental results. Therefore, the used oil burner-based pyrolysis prototype with a simple condensation system can be declared technically feasible and meets the research objectives.

CONCLUSION

Based on the design, simulation, and experimental validation conducted in this study, the prototype of a plastic waste pyrolysis system using a waste-oil burner and a simple condensation system has demonstrated satisfactory technical performance and strong compatibility between software simulation and real testing results. The 3D design developed in SolidWorks successfully integrated all major components of the system, while thermal analysis using ANSYS showed a consistent and gradual temperature decrease from the reactor to the condenser outlet, in accordance with steady-state heat transfer principles. The waste-oil burner was capable of maintaining an operating temperature range of 300–500°C, enabling the effective pyrolysis of ±2 kg of PP and PET plastic materials. The condensation system effectively reduced vapor temperature to approximately 30°C, indicating efficient conversion of pyrolysis vapor into liquid oil. Although minor deviations were observed between simulation and experimental data due to combustion stability, airflow variations, and environmental conditions, these differences remained within acceptable limits for a small-scale system. Overall, the prototype design is technically feasible and has strong potential for further development as an efficient, economical, and environmentally friendly small-scale plastic waste processing technology.

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