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GREENATION RESEARCH

Design of a Miniature Plastic Waste Pyrolysis Machine Prototype Based on a Used Oil Burner with a Simple Condensation System

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Abstract: This study aims to design, realize, and evaluate the performance of a mini-scale plastic waste pyrolysis machine prototype based on a used oil burner with a simple condensation system. The research methods include design, fabrication of main components, system assembly, and thermal performance testing for 60 minutes. Test results show that the reactor reached a maximum temperature of 346°C at 40 minutes and maintained a stable temperature of around 325°C. The spiral condensation system was able to convert pyrolysis vapor into liquid oil. The developed prototype has the potential to be an alternative mini-scale waste-to-energy plastic waste treatment technology that is economical and applicable.

Keyword: Plastic Pyrolysis, Used Oil Burner, Batch Reactor, Spiral Condenser, Mini-Scale Prototype.

INTRODUCTION

The increasing volume of plastic waste in Indonesia has become a serious environmental issue due to its non-biodegradable characteristics. Improper waste management can lead to soil, water, and air pollution. One of the widely developed methods for converting plastic waste is pyrolysis, a thermal decomposition process conducted in the absence of oxygen that produces oil, gas, and solid residue [1].

Pyrolysis typically operates at temperatures ranging from 300–500°C; therefore, the reactor design must withstand thermal loads and internal pressure during operation. Material selection is a critical aspect of system design. Carbon steel is commonly used in thermal equipment construction due to its good mechanical strength, ease of fabrication, and relatively low cost [2]. However, stress analysis and thermal expansion considerations are necessary to ensure structural safety under high-temperature conditions [3].

In this study, the heating system utilizes a waste-oil burner as an alternative energy source. The use of waste oil aims to improve operational cost efficiency while promoting energy waste utilization. The burner structure, fabricated through welding processes, must possess adequate joint strength to resist thermal loads during combustion [4].

In addition to the heating system, the condensation system plays a crucial role in converting hydrocarbon vapor into liquid form through heat transfer mechanisms. The effectiveness of condensation is influenced by heat transfer surface area, material thermal conductivity, and the temperature difference between vapor and cooling media [5]. Therefore, proper selection of condenser pipe material is essential in the system design.

Based on these considerations, this study aims to design and construct a small-scale pyrolysis machine prototype utilizing a waste-oil burner with a simple condensation system. The research focuses on evaluating reactor material strength, the reliability of the welded burner system, and the performance of the condensation system in producing pyrolysis oil.

METHOD

The research flow framework is a systematic sequence that outlines the entire research process, starting from planning and design, followed by fabrication and testing, and ending with data analysis. The research flow is presented as follows:
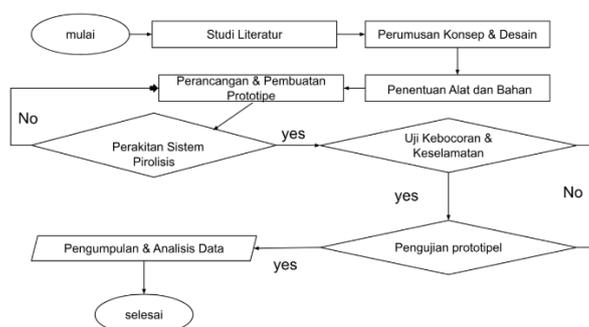

Figure 1. Research Flowchart

Literature Study

The initial stage of designing a literature study aims to obtain theoretical foundations and scientific references relevant to the research topic. The literature study was conducted by studying textbooks, scientific journals, proceedings, and research reports related to: Miniature pyrolysis reactor design and working principles, Working principles of used oil burners as heat sources, and Condensation systems in the pyrolysis process.

Concept and Design Formulation Stage

Formulation of the design concept to be developed. This stage determines the initial specifications of the pyrolysis system so that it is in line with the design objectives and can be applied on a mini scale. The main concept of the design utilizes the heat energy from the combustion of used oil as a heat source for the pyrolysis process of plastic waste in the reactor. The steam produced by pyrolysis is then fed into a simple condensation system to be cooled in a water container and converted into pyrolysis oil.

Tools and Materials for Designing Pyrolysis;

**Table 1. Tools Used in the Pyrolysis Reactor Fabrication**

No	Equipment	Specification
1	Electric welding machine	220 V
2	Hand grinder	4-inch disc
3	Cordless drill	Portable type
4	Vernier caliper	±0.02 mm accuracy
5	Measuring tape	5 m
6	Infrared thermometer (CX-6000)	−50°C to 600°C
7	Pressure gauge	PSI/Bar scale

Table 2. Materials Used in the Pyrolysis System

No	Material	Specification
1	Carbon steel plate	Reactor material
2	Galvanized pipe	Vapor/gas line
3	Water drum	Condensation medium
4	Epoxy metal adhesive	Sealing material
5	PE/PP plastic	Feedstock
6	Used oil	Burner fuel
7	Snail blower with dimmer	Airflow control
8	SGP welding elbow	Pipe connection
9	Valve tap	Flow control
10	Welding electrode	SMAW electrode

System Design

The pyrolysis reactor prototype was constructed using carbon steel plates with a thickness of approximately 3–5 mm in a vertical cylindrical configuration. The material was selected due to its adequate mechanical strength, weldability, and suitability for operation within the typical plastic pyrolysis temperature range of 300–500°C.
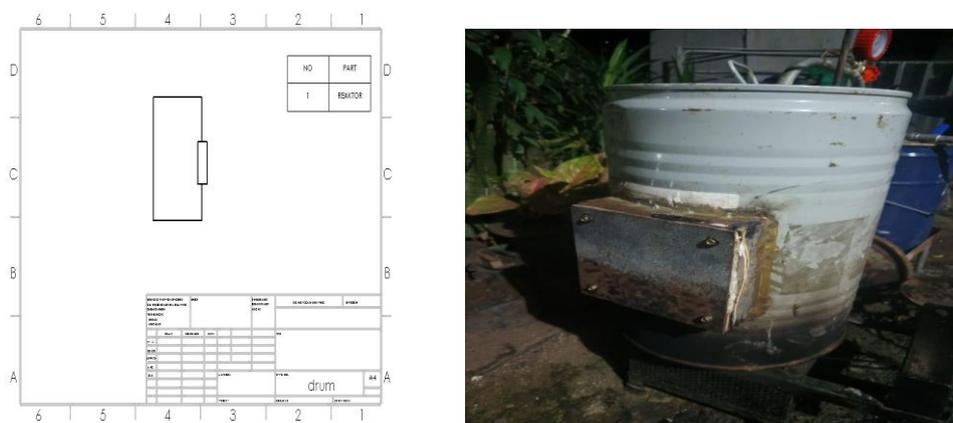

Figure 2. pyrolysis reactor prototype

Table 3. Table. Reactor Design Specifications

No	Parameter	Specification
1	Reactor Type	Batch
2	Material	Carbon steel plate
3	Plate Thickness	3–5 mm
4	Shape	Vertical cylinder
5	Capacity	1–2 kg plastic per batch
6	Sealing System	Welded and bolted
7	Vapor Outlet Diameter	± ½ inch

The pyrolysis reactor prototype is designed in a vertical cylindrical shape with a capacity of 1–2 kg of plastic per batch. This reactor is made of 3–5 mm thick carbon steel plate so that it can withstand high temperatures (>600 °C) while also having good mechanical strength. The cover system uses a combination of welding and bolts, with a steam outlet diameter of ±½ inch, in accordance with the specifications for the batch reactor type.

Used oil burner Prototype Used oil burner The Used Oil Burner is installed at the bottom of the reactor and functions as the main heat source. The burner uses used oil as fuel with the help of a 220 V blower to supply air in control using a dimmer.
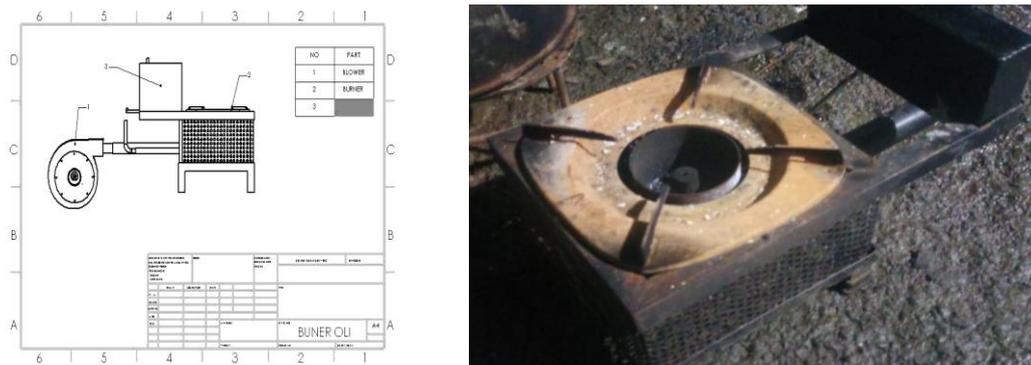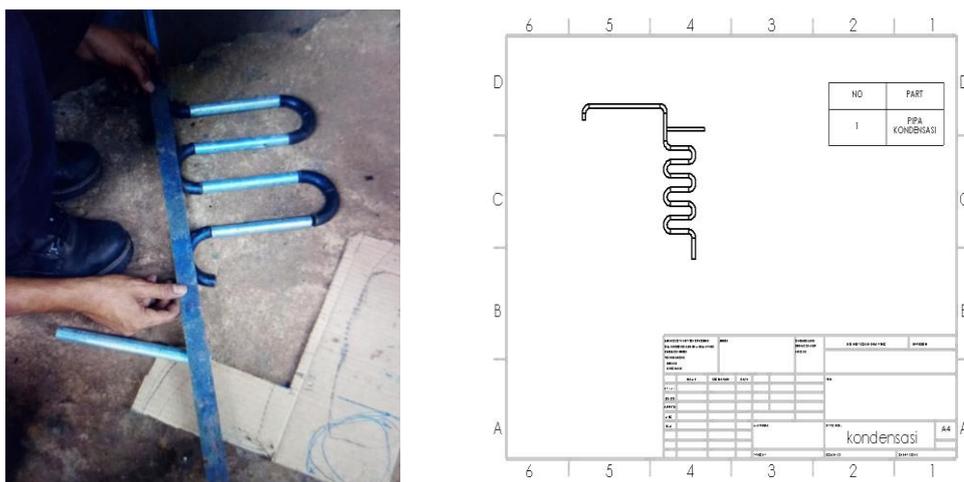
Figure 3 Used oil burner Prototype

Table 4. Burner System Specifications

No	Description	Specification
1	Oil reservoir tank	2 mm steel plate, $20 \times 10 \times 5$ cm
2	Burner pipe diameter	± 1 inch
3	Burner pipe length	± 400 mm
4	Air supply system	220 V snail blower
5	Airflow intensity control	Dimmer
6	Frame material	2×2 cm hollow steel
7	Oil outlet valve	¾ inch

The burner system was designed to provide stable and controllable heat to the pyrolysis reactor. The fuel tank was fabricated from 2 mm steel plate ($200 \times 100 \times 50$ mm). The burner pipe had a diameter of approximately 25.4 mm and a length of 400 mm to ensure stable combustion. Air supply was delivered by a 220 V centrifugal blower and regulated using an electronic dimmer to control flame intensity. The frame was constructed from 20×20 mm hollow steel, and a 19.05 mm outlet valve was installed to regulate fuel flow during operation.

The condensation system is designed using spiral pipes (coil condensers) immersed in a water tank. The pyrolysis vapor is channeled through the spiral pipes, where it is cooled and converted into a liquid form of pyrolysis oil, which is then collected in a storage container.\

Figure 4 Used oil burner Prototype

Table 5. Condenser System Specifications

No	Description	Specification	Remarks
1	Condenser type	Spiral (coil) pipe	Water cooling
2	Pipe material	Galvanized steel	Thermal conductivity
3	Cooling medium	Water	Static system
4	Cooling method	Indirect	–
5	Pipe configuration	Spiral	Increased contact area
6	Output product	Pyrolysis oil	Liquid phase
7	System scale	Prototype	Laboratory scale

The condenser system employed a spiral (coil) pipe configuration to enhance heat exchange efficiency. Galvanized steel was selected as the pipe material due to its adequate thermal conductivity and structural strength. Water was used as a static cooling medium in an indirect cooling process to condense pyrolysis vapors into liquid oil. The system was developed at a laboratory-scale prototype level.

RESULT AND DISCUSSION
Assembly of the Pyrolysis Prototype

The fabrication and assembly process was conducted according to the predetermined design specifications. The supporting frame was assembled first to ensure structural stability during operation. The reactor was mounted vertically and secured using welded joints and bolted connections to prevent excessive displacement during heating.

The used-oil burner was installed beneath the reactor to provide uniform thermal distribution along the reactor wall. The vapor outlet was connected to a spiral pipe condenser system, which was linked to a liquid collection container. Prior to testing, all weld joints and pipe connections were inspected to prevent leakage and ensure operational safety.
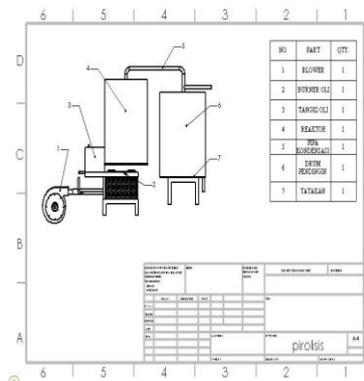
Figure 5. Overall Assembly of the Pyrolysis Prototype

Structural Strength Analysis

Structural evaluation was performed using static load analysis. The total gravitational load acting on the frame is calculated as:

$$W = m \cdot g$$

Where:
m = 18 kg
g = 9,81 m/s^2

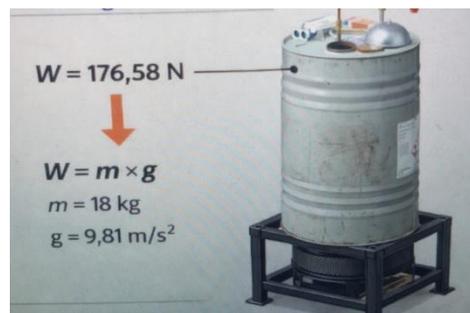$$W = 18 \times 9,81 = 176,58 \text{ N}$$

Figure 6. Static Load Distribution

Assuming uniform load distribution across four supporting legs:

$$W_{leg} = \frac{W}{4} = 44.15 \text{ N}$$

The compressive stress on the hollow steel frame is determined by:

$$\sigma = \frac{F}{A}$$

Cross-sectional area:

$$A = (20 \times 20) - (17 \times 17) = 111 \text{ mm}^2$$

$$\sigma = \frac{44.15}{111} = 0.398 \text{ MPa}$$

Allowable stress:

$$\sigma_{allow} = \frac{\sigma_y}{SF}$$

With:

$$\sigma_y = 250 \text{MPa}$$
$$SF = 3$$
$$\sigma_{allow} = 83.3 \text{ MPa}$$

Since $\sigma_{working} < \sigma_{allow}$, the frame is structurally safe under static loading conditions.

Figure 7. Structural Load Distribution on Supporting Frame

Reactor Performance Testing

The reactor was tested using 2 kg of mixed PE and PP plastic. The operating conditions are summarized below.

Table 6. Reactor Testing Conditions

Parameter	Description
Plastic Type	Mixed PE and PP
Feed Mass	2 kg
Heat Source	Used-oil burner
Heating Time	60 minutes
Maximum Temperature	346°C
Condenser Pipe	½ inch galvanized
Cooling Water Volume	20 L

Temperature Profile Analysis

Temperature was recorded at regular intervals during heating. The results are shown below.

Table 7. Reactor Temperature vs Time

Time (min)	Temperature (°C)
0	30
10	153
20	222
30	276
40	346
55	325
60	325

The heating rate is calculated as:

$$\text{Heating Rate} = \frac{\Delta T}{\Delta t}$$
$$= \frac{346 - 30}{40} = 7.9°C/min$$

The reactor reached 346°C within 40 minutes, exceeding the minimum pyrolysis temperature (>300°C). After reaching peak temperature, the system stabilized at approximately 325°C due to heat losses and manual combustion control.
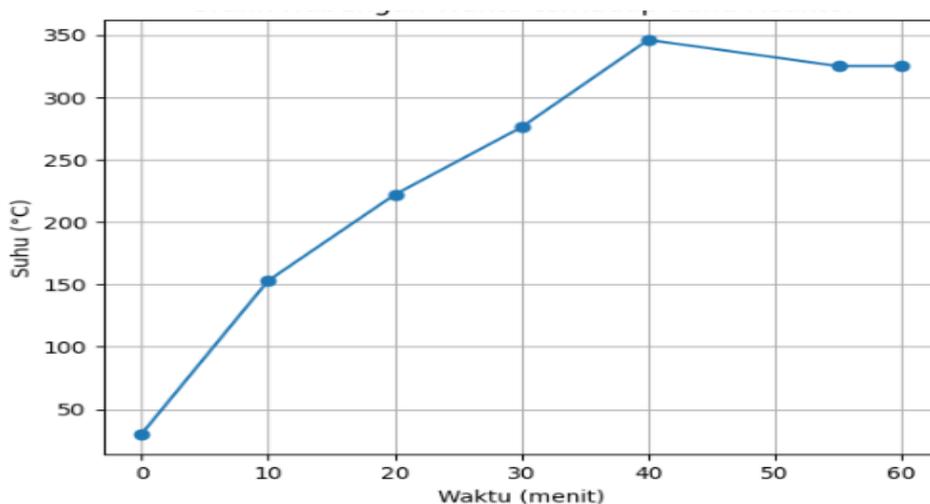
Figure 8. Reactor Temperature Profile

Fuel Consumption Analysis

Fuel consumption was evaluated using:

$$\text{Fuel Consumption} = V_i - V_f$$

Table 8. Fuel Consumption Data

Time (min)	Initial Volume (mL)	Final Volume (mL)	Comsumtion (mL)
20	500	350	150
40	500	200	300
60	500	50	450

At 60 minutes, total fuel consumption reached 450 mL, indicating stable combustion performance throughout operation

Condenser Performance Evaluation

The condenser system was designed using a spiral galvanized pipe immersed in a water cooling medium to ensure sufficient heat removal for vapor condensation during batch pyrolysis operation.The vapor mass flow rate was estimated based on the pyrolysis of 2 kg mixed plastic with an assumed vapor conversion fraction of 50% over a 60-minute operating period:

$$Q_v = \frac{m_{plastic} \cdot \alpha}{t}$$
$$Q_v = \frac{2 \times 0.5}{3600} = 2.78 \times 10^{-4} \text{kg /s}$$

A pipe diameter of ½ inch (0.0127 m) was selected to maintain adequate vapor velocity while avoiding excessive pressure drop. The total pipe length was designed as 2 m in spiral configuration to increase the heat transfer contact area. The external heat transfer surface area was estimated as:

$$A = \pi D L$$
$$A = \pi \times 0.0127 \times 2 = 0.08 \ m^2$$

The cooling capacity of the condenser was evaluated using the energy balance of the cooling water. With 20 L of water, inlet temperature of 25°C, and outlet temperature of 40°C:

$$Q = mc\Delta T$$
$$Q = 20 \times 4186 \times (40 - 25) = 1.25 \times 10^6 \ J$$

This heat removal capacity indicates that the condenser is thermally sufficient to condense the pyrolysis vapor generated in one batch operation.
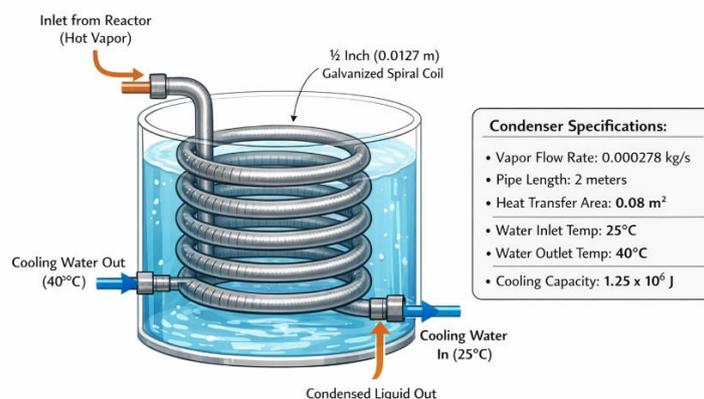
Figure 9. Spiral condenser design with indirect water cooling system

The figure illustrates a ½ inch galvanized spiral pipe immersed in a water bath. Hot pyrolysis vapor enters the coil and releases heat to the cooling water (25–40°C), enabling phase change into liquid oil. The design provides an estimated heat transfer area of 0.08 m² and cooling capacity of 1.25×10^6 J.

The calculated condenser capacity supports the experimental observation that pyrolysis vapor was successfully converted into liquid oil during reactor operation at a maximum temperature of 346°C.

Table 9. Condenser Performance Evaluation

Indicator	Observation
Vapor at outlet	Not significant
Liquid oil formation	Observed
System leakage	None

The condenser system successfully converted pyrolysis vapors into liquid oil under laboratory-scale conditions. However, the static cooling method may limit condensation efficiency during extended operation.

Overall Performance Evaluation

The prototype successfully achieved the intended design objectives. Structural analysis confirmed mechanical safety with a high safety margin. The burner system generated sufficient thermal energy to reach the required pyrolysis temperature range, and the condenser system functioned effectively.

Nevertheless, performance limitations were identified, including heat loss due to lack of thermal insulation and manual airflow regulation. Future improvements should include thermal insulation, PID-based temperature control, and a circulating cooling system to enhance efficiency and operational stability.

CONCLUSION

A laboratory-scale batch pyrolysis reactor equipped with a used-oil burner and spiral condenser system was successfully designed and fabricated. Structural evaluation indicated that the $20 \times 20 \times 1.5$ mm hollow steel frame operates within safe stress limits under static loading conditions.

Thermal testing showed that the reactor reached a maximum temperature of 346°C within 40 minutes, exceeding the minimum temperature required for plastic pyrolysis (>300°C). The average heating rate was 7.9°C/min, demonstrating sufficient heat transfer performance of the combustion system. Fuel consumption during operation was recorded at approximately 450 mL per 60 minutes, indicating stable burner operation.

The spiral-type galvanized condenser effectively condensed pyrolysis vapors into liquid oil without observable leakage, confirming proper system performance at prototype scale.

Despite satisfactory performance, temperature fluctuations were observed due to heat losses and manual airflow regulation. Therefore, the integration of thermal insulation and automatic temperature control is recommended to improve thermal efficiency and operational stability in future development.

Overall, the developed prototype demonstrates technical feasibility for small-scale experimental applications in plastic waste pyrolysis.

The novelty of this study lies in the integration of a low-cost used-oil burner with a compact spiral condenser for laboratory-scale plastic waste pyrolysis.

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