THERMAL PERFORMANCE AND ECONOMIC ANALYSIS OF A 150-LITER CAPACITY PYROLYSIS REACTOR USING POLYPROPYLENE (PP) PLASTIC WASTE

Dhidik Mahandika[1]*, Eka Maulana[1], Hendri Sukma[1], Joseba Giansena[1]
[1]Program Studi Teknik Mesin, Universitas Pancasila, Jakarta, 12640, Indonesia
*Email Corresponding Author: dhidik_mahandika@univpancasila.ac.id

ABSTRAK

Sampah plastik dapat diolah menjadi minyak melalui proses pirolisis. Namun, proses tersebut memerlukan energi panas sehingga penggunaan bahan bakarnya perlu diperhatikan. Penelitian ini membahas kinerja reaktor pirolisis berkapasitas 150 liter berdasarkan data pengujian dalam tugas akhir. Bahan yang digunakan adalah plastik polipropilena (PP) sebanyak 10 kg dengan LPG sebagai sumber panas. Pengujian berlangsung selama 240 menit pada temperatur 30–350 °C. Data yang dianalisis meliputi perubahan temperatur, pemakaian LPG, volume minyak, sifat minyak hasil pirolisis, neraca energi, dan biaya proses. Hasil pengujian menunjukkan bahwa 10 kg plastik PP menghasilkan 9 liter minyak dengan penggunaan LPG sebanyak 12 kg. Rata-rata produksi minyak selama pengujian adalah 2,25 liter/jam. Hasil uji laboratorium menunjukkan angka oktan riset 83,6 dan massa jenis 781 kg/m³ pada temperatur 15 °C. Dengan harga PP Rp2.000,-/kg dan LPG Rp19.000,- per tabung 3 kg, dihasilkan biaya proses sebesar Rp96.586,- sedangkan nilai produk Rp90.000,- sehingga terdapat selisih negatif Rp6.586,-. Reaktor telah mampu menghasilkan minyak dari plastik PP, tetapi konsumsi LPG yang tinggi masih menjadi kendala utama.
Kata Kunci : Polipropilena; Pirolisis; Minyak Pirolisis

ABSTRAK

Plastic waste can be converted into oil through pyrolysis. However, this process requires thermal energy; therefore, fuel consumption needs to be considered. This study discusses the performance of a 150-liter pyrolysis reactor based on experimental data reported in an undergraduate thesis. The material used was 10 kg of polypropylene (PP) plastic, with liquefied petroleum gas (LPG) as the heat source. The experiment was conducted for 240 minutes over a temperature range of 30–350 °C. The analyzed data included changes in temperature, LPG consumption, oil volume, characteristics of the resulting pyrolysis oil, energy balance, and process costs. The results showed that 10 kg of PP plastic produced 9 liters of oil while consuming 12 kg of LPG. The average oil production rate during the experiment was 2.25 liters/hour. Laboratory tests showed a research octane number of 83.6 and a density of 781 kg/m³ at 15 °C. With a PP price of IDR 2.000,-/kg and an LPG price of IDR 19.000,- per 3-kg cylinder, the reported process cost was IDR 96.586,- while the product value was IDR 90.000,- resulting in a deficit of IDR 6.586,-. The reactor was able to produce oil from PP plastic, but high LPG consumption remains the main challenge.

Keyword: ***Polypropylene; pyrolysis; pyrolysis oil***

I. INTRODUCTION

Plastic waste is difficult to degrade naturally and can cause environmental problems. One of the most commonly used plastics is polypropylene (PP). PP plastic can be processed through pyrolysis, which involves heating in the absence of oxygen or with only a small amount of oxygen, to produce oil, gas, and solid residues. The products of this process are influenced by temperature, heating duration, plastic type, and reactor conditions [1]–[3].

Several studies have discussed PP plastic pyrolysis. According to Papuga et al. [1], feedstock mass and reactor temperature affect the quantity of oil produced. Uebe et al. [2] explained that the properties of pyrolysis oil must be tested before it is used as fuel. In addition to oil production, energy consumption and operating costs must also be considered [3], [4].

This research covers testing of a 150-liter pyrolysis reactor using PP waste as feedstock and LPG for heating. The available data include temperature, oil production, LPG consumption, oil-property testing, energy calculations, and operating costs for evaluating reactor performance. However, several energy calculations contain differences in units and assumptions that need to be explained. The objectives are to discuss temperature changes and oil production, calculate LPG consumption, and review the energy balance and operating costs.

II. RESEARCH METHODS

Research Object and Materials

The research object was a pyrolysis reactor with a nominal capacity of 150 liters. The feedstock consisted of 10 kg of shredded and dried PP plastic waste. The reactor was heated using LPG, and the vapor produced was directed to a condenser to obtain liquid oil.

Table 1. Characteristics of PP Waste

Parameter	Value
Density	920 kg/m³
Melting point	130 °C
Heat of vaporization (U)	4.240 kJ/kg
Heat of fusion (L)	207 kJ/kg
Specific heat capacity (Cp)	1,64 kJ/(kg·°C)

Tabel 2. Experimental Parameters

Parameter	Value
Reactor capacity	150 liters
PP feedstock	10 kg
Total LPG consumption	12 kg
Test duration	240 minutes (4 hours)
Temperature range	30–350 °C
Maximum furnace temperature	512 °C

Experimental Setup and Procedure

The reactor was heated using LPG. Vapor formed from the breakdown of the plastic was passed through the condenser, where it was collected as oil. Heating was conducted for 240 minutes over the temperature range of 30–350 °C.

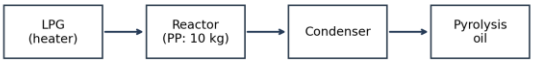


Figure 1. Conceptual flow of heating and condensation.

Data Collection

The measured variables were temperature (°C), cumulative LPG consumption (kg), and cumulative oil volume (liters). The resulting pyrolysis oil was then tested in a laboratory to determine its research octane number using ASTM D2699 and its density using ASTM D4052. Cost data were obtained from feedstock, LPG, electricity, and estimated product values.

Data Processing

The experimental data were processed using simple calculations. Oil productivity was calculated by dividing oil volume by processing time, while specific LPG consumption was calculated by dividing LPG mass by oil volume:

$$P_v = \frac{V_m}{t} \quad (1)$$

$$q_{LPG} = \frac{m_{LPG}}{V_m} \quad (2)$$

In Equation (1), P_v denotes oil productivity (liters/hour), V_m is oil volume (liters), and t

is processing time (hours). In Equation (2), qLPG denotes specific LPG consumption (kg/liter of oil), and mLPG is LPG mass (kg). Oil mass was estimated using the laboratory-measured density:

$$m_m = \rho V_m \quad (3)$$

where m_m is oil mass (kg) and ρ is oil density (kg/liter). Economic performance was assessed as the difference between product value and total operating costs:

$$S = R - C \quad (4)$$

In Equation (4), S is the difference between product value and costs (IDR), R is product value (IDR), and C is total operating costs (IDR).

III. RESULTS AND DISCUSSION

Based on the experimental results in Table 2, the average heating rate from 30 °C to 350 °C was approximately 1,33 °C/minute.

Tabel 3. Data Pengujian Selama 240 Menit

Time (min)	Temp (°C)	LPG (kg)	Oil (L)
0	30	0	0
30	102	1,5	0
60	150	3	0
90	202	4,5	0,3
120	241	6	2,1
150	287	7,5	3,8
180	336	9	5
210	350	10,5	7,2
240	350	12	9

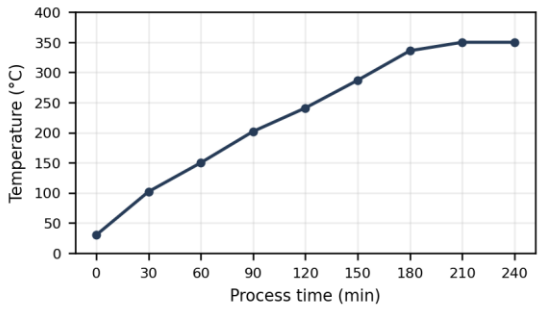


Figure 2. Temperature changes over time

The first oil was recorded at minute 90, with a volume of 0,3 liters, when the reactor temperature was 202 °C. As shown in Figure 3, the rate of oil formation was not completely uniform.

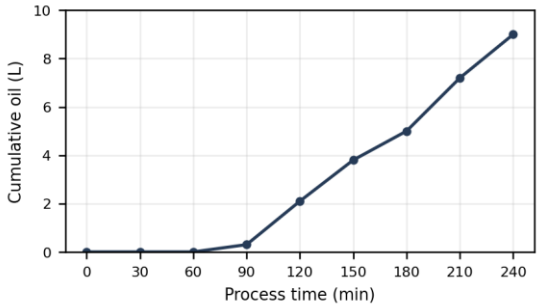


Figure 3. Cumulative oil volume during the experiment

This trend indicates that temperature and heating time affected oil production. Production of 9 liters of oil in 4 hours corresponds to an average productivity of 2,25 liters/hour. For 10 kg of PP, oil production was 0,90 liters/kg of PP.

LPG Consumption

At the initial stage, heat from LPG combustion was used to raise the temperature of both the reactor and the feedstock. Pyrolysis oil only began to accumulate at minute 90, reaching 0,3 liters. LPG consumption was 1.,5 kg every 30 minutes, equivalent to an average rate of 3 kg/hour and a total of 12 kg after 240 minutes.

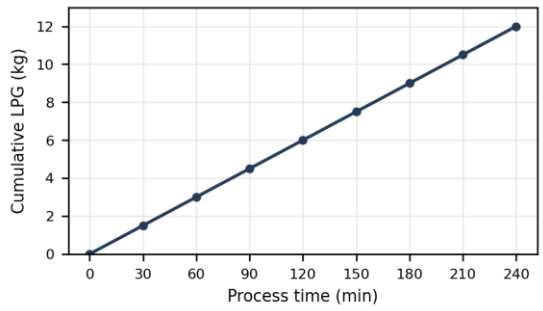


Figure 4. Cumulative LPG consumption over 240 minutes

Octane Number Testing (ASTM D2699)

Octane number testing was carried out to determine the ability of the pyrolysis oil to resist knocking in a gasoline engine. ASTM D2699 is a standard test method for determining the Research Octane Number (RON) of liquid fuels. Its principle is to compare the combustion characteristics of a sample with reference fuels using a standard Cooperative Fuel Research (CFR) engine. The higher the octane number, the greater the fuel's resistance to knocking.

Based on laboratory testing, the pyrolysis oil produced from polypropylene (PP) plastic waste had an octane number of 83,6. This value indicates that the resulting pyrolysis oil exhibits a measurable level of knock resistance.

Density Testing (ASTM D4052)

Density testing was carried out to identify the physical properties of pyrolysis oil produced from polypropylene (PP) plastic waste. The test followed ASTM D4052 using a digital density meter. The measurement principle involves determining the change in oscillation frequency of a U-shaped tube (oscillating U-tube) after it is filled with an oil sample. This change in frequency is used to calculate the liquid density based on the instrument calibration.

Laboratory test results showed that the pyrolysis oil had a density of 781 kg/m³ at a temperature of 15 °C.

Energy Balance

The summarized energy-balance calculations for the pyrolysis process and LPG combustion are presented in Table 3. The heat input of 16.303,85 kJ/hour equals the sum of heat absorbed by the system (14.331,5 kJ/hour) and the heat output (1.972,35 kJ/hour).

Table 4. Pyrolysis Energy Balance

Energy	Description	Unit	Reported value
ΔQgenerated	Heat generated	kJ/hour	14.331,5
ΔQout	Heat output	kJ/hour	1.972,35
ΔQin	Heat input	kJ/hour	16.303,85

Table 5. Combustion Energy Balance

Energy / parameter	Note	Unit	Reported value
ΔQ combustion (total)		kJ/hour	20.379,81
Heat absorption efficiency	80%		
ΔQ gas combustion		kJ/hour	150,306
m gas		kg/hour	3
HHV gas		kJ/kg	50,102
ΔQ LPG combustion		kJ/hour	20.229,504

Table 6. Summary of Energy Balance

Energy component	kJ/hour (reported)	kW (reported)
Energy consumed		39,33
Electricity		0,1
LPG	14,1243	39,23
Energy (products)		41,569
Gasoline	64.798,5	17,99
Diesel	82.786,875	22,99
Exhaust gas	150,306	0,041
Condenser	1.972,35	0,548
Net energy		2,239

Operating Cost Analysis

Operating costs were calculated using feedstock and LPG prices of IDR 2.000/kg

for PP plastic and IDR 19.000 for each 3-kg LPG cylinder. For 10 kg of PP, the feedstock cost was IDR 20.000. The 12 kg of LPG consumed corresponded to four 3-kg cylinders, resulting in an LPG cost of IDR 76.000. The electricity cost was calculated from a pump power of 0,1 kW operating for 4 hours at a tariff of IDR 1.467,28/kWh, giving approximately IDR 587. The product value was estimated as 9 liters of a gasoline fraction at IDR 10.000/liter, resulting in a reported deficit of IDR 6.586. The reactor was able to produce oil from PP plastic, but high LPG consumption remained the main obstacle.

Table 7. Operating Cost Calculation

Expenditure			
Item	**Quantity**	**Unit price**	**Amount (IDR)**
PP plastic	10 kg	IDR 2.000	20.000
LPG (3-kg cylinder)	4 cylinders	IDR 19.000	76.000
Electricity (4 hours)	0,4 kWh	IDR 1.467	587
Total			96.587
Incone			
Item	**Quantity**	**Unit price**	**Amount (IDR)**
Gasoline	9 liters	IDR 10.000	90.000
Total			90.000

IV. CONCLUSION

Testing of the 150-liter pyrolysis reactor using 10 kg of PP plastic for 240 minutes produced 9 liters of oil. The temperature increased from 30 °C to 350 °C, and LPG consumption was 12 kg. Average oil productivity was 2,25 liters/hour, with specific LPG consumption of 1,33 kg per liter of oil. Laboratory tests showed a research octane number of 83,6 and an oil density of 781 kg/m³ at 15 °C. The reactor was capable of producing oil from PP plastic waste, but high LPG consumption remained the main obstacle.

REFERENCE

[1] Papuga S, Savković J, Djurdjevic M, Ciprioti SV. Effect of feed mass, reactor temperature, and time on the yield of waste polypropylene pyrolysis oil produced via a fixed-bed reactor. Polymers 2024; 16(10): 1302. doi: 10.3390/polym16101302.

[2] Uebe J, Kryzevicius Z, Majauskiene R, Dulevicius M, Kosychova L, Zukauskaite A. Use of polypropylene pyrolysis oil in alternative fuel production. Waste Management & Research 2022; 40(8): 1220-30. doi: 10.1177/0734242X211068243.

[3] Laghezza M, Fiore S, Berruti F. A review on the pyrolytic conversion of plastic waste into fuels and chemicals. Journal of Analytical and Applied Pyrolysis 2024; 179: 106479. doi: 10.1016/j.jaap.2024.106479.

[4] Yaqoob H, Ali HM, Khalid U. Pyrolysis of waste plastics for alternative fuel: a review of key factors. RSC Sustainability 2025; 3(1): 208-18. doi: 10.1039/D4SU00504J.

[5] Jung H, Ahn Y. Process design for plastic waste pyrolysis: yield analysis and economic assessment. Computers & Chemical Engineering 2025; 194: 109001. doi: 10.1016/j.compchemeng.2025.109001.

[6] P. Purwaningrum, “Upaya mengurangi timbulan sampah plastik di lingkungan,” *Jurnal Teknik Lingkungan*, vol. 8, no. 2, pp. 141–147, 2019.

[7] D. Iswadi, F. Nurisa, and E. Liastuti, “Pemanfaatan sampah plastik LDPE dan PET menjadi bahan bakar minyak dengan proses pirolisis,” *Jurnal Ilmiah Teknik Kimia UNPAM*, vol. 1, no. 2, 2017.

[8] A. S. Nugroho, “Pemanfaatan limbah plastik sebagai energi alternatif,” *Jurnal Simetris*, vol. 9, no. 1, pp. 55–60, 2018.

[9] D. G. H. Adoe, W. Bunganaen, I. F. Krisnawi, and F. A. Soekwanto, “Pirolisis sampah plastik PP (polypropylene) menjadi

minyak pirolisis sebagai bahan bakar primer," *LJTMU*, vol. 3, no. 1, pp. 17–26, 2016.

[10] G. L. Sari, "Kajian potensi pemanfaatan sampah plastik menjadi bahan bakar cair," *Jurnal Teknik Lingkungan*, vol. 3, no. 1, pp. 6–13, 2017.

[11] I. Rekathakusuma, D. Suwandi, and Asep S., "Karakterisasi bahan cair produk distilasi sampah plastik dan pemanfaatannya sebagai bahan bakar," *e-Proceeding of Engineering*, vol. 3, no. 3, pp. 4853–4862, 2016.

[12] Sumartono, "Produksi bahan bakar minyak dari limbah plastik HDPE dan PETE 1 kg," in *Prosiding SEMNASTEK UISU*, 2019.

[13] Sumartono, H. Ibrahim, and Sarjianto, "Uji karakteristik bahan bakar minyak (BBM) dari limbah plastik," *IRWANS*, vol. 9, no. 60, pp. 380–385, 2012.

[14] E. Kurniawan and Nasrun, "Karakterisasi bahan bakar dari sampah plastik jenis high density polyethylene (HDPE) dan low density polyethylene (LDPE)," *Jurnal Teknologi Kimia Unimal*, vol. 2, no. 3, pp. 41–52, 2014.

[15] S. Dayana, A. Sharuddin, F. Abnisa, W. Mohd, and A. Wan, "A review on pyrolysis of plastic wastes," *Energy Conversion and Management*, vol. 115, pp. 308–326, 2016.

[16] M. A. Alexander, "Neraca massa dan neraca energi pengelolaan sampah terpadu – Penujah Kabupaten Tegal," *Jurnal Ilmiah Teknobiz*, vol. 8, no. 3, pp. 129–138, 2019.

[17] R. Sirait, E. Maulana, and D. Mahandika, "Analisis keseimbangan energi pada reaktor pirolisis kapasitas 75 kg/jam," in *Prosiding Seminar Nasional Penelitian LPPM UMJ*, Jakarta, Indonesia, Oct. 7, 2020, pp. 47–55.