

Reproducible Thermodynamic Modelling and Energy-Normalized Assessment of a Small-Scale Plastic Pyrolysis Reactor for PE, PP, and HDPE Waste

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Abstract: Pyrolysis offers a promising route for recovering liquid hydrocarbons from difficult-to-recycle polyolefin waste; however, small-scale reactor studies can provide incomplete assessment when reported oil production is not considered together with the thermal energy required to heat the feedstock, reactor hardware, and compensate for heat losses. This study develops a transparent and reproducible thermodynamic framework for a small-scale pyrolysis reactor processing polyethylene (PE), polypropylene (PP), and high-density polyethylene (HDPE). The model was formulated using direct mass- and energy-balance equations based on the reported fabricated reactor geometry, a 3 kg batch basis, literature-derived thermophysical properties, polymer fusion and pyrolysis enthalpies, reactor-wall heating, and heat-loss calculations. A deterministic MATLAB implementation was used to evaluate thermal input over 400–550 °C and to assess the sensitivity to insulation thickness from 10 to 50 mm. Model outputs were assessed against the reported final plastic-waste-oil (PWO) volumes, while experimental observations, literature-derived properties, modelling assumptions, and legacy numerical results were kept explicitly separated. At 500 °C, the calculated thermal inputs were 10.67 MJ for PE, 10.88 MJ for PP, and 14.00 MJ for HDPE. Increasing the assumed insulation thickness from 10 to 50 mm reduced the calculated thermal input by approximately 9.3–12.0%. The reported PWO volumes were 1.50 L for PE, 1.40 L for HDPE, and 0.90 L for PP. Under a common 500 °C reference condition, the corresponding reference energy-normalized oil-recovery indices (REORI) were 0.141, 0.100, and 0.083 L MJ⁻¹, respectively. REORI provides a common-basis comparative screening indicator by relating reported PWO volume to modelled thermal input, but it should not be interpreted as measured process efficiency. The framework demonstrates the importance of considering reactor thermal mass and heat-loss control alongside feedstock properties when assessing small-scale pyrolysis systems. However, the analysis is limited by the unavailability of direct heater-energy measurements, calibrated reaction-zone temperature data, cooling-water flow records, replicate measurements, and complete primary experimental records. Future work should therefore incorporate direct heater-power or energy-consumption measurements, calibrated reaction-zone temperature monitoring, oil mass-yield determination, condenser heat-removal measurements, and replicated experiments to enable rigorous energy-efficiency evaluation and validation of the thermodynamic framework.

Keywords: Energy Assessment, MATLAB, Plastic Pyrolysis, Polyolefins, Thermodynamic Modelling.



1. Introduction

The accumulation of post-consumer plastic waste has become a major environmental and resource-management challenge, particularly for heterogeneous and contaminated polymer streams that are difficult to process through conventional mechanical recycling. Thermochemical conversion by pyrolysis has therefore attracted considerable attention as a route for converting hydrocarbon-rich plastic waste into liquid hydrocarbons, permanent gases, and solid residues while recovering chemical value from materials that are otherwise difficult to recycle [1] [2]. Polyolefin-based wastes, particularly polyethylene (PE), polypropylene (PP), and high-density polyethylene (HDPE), are especially relevant because of their high hydrocarbon content and widespread occurrence in post-consumer plastic waste. Recent research has consequently investigated feedstock composition, operating temperature, reactor configuration, catalysts, product distribution, and process optimization to improve liquid-product recovery and energy utilization [3] [4].

Despite these developments, the assessment of small-scale plastic pyrolysis systems remains challenging because process performance depends not only on the chemical characteristics of the feedstock but also on the thermal behaviour of the reactor itself [5]. In particular, the energy required to heat the polymer charge and the reactor wall, together with heat losses to the surroundings, can represent a substantial portion of the total thermal requirement. Consequently, reported oil production alone does not provide a sufficient basis for comparing the thermal performance of different feedstocks or reactor configurations [6]. A physically realistic assessment should account for the coupled contributions of feedstock heating, phase-change and pyrolysis enthalpies, reactor thermal mass, and external heat losses [7].

Thermodynamic and energy-based modelling has been increasingly applied to evaluate energy requirements and thermal behaviour in pyrolysis systems. Such approaches can provide useful estimates of heat demand, temperature-dependent energy requirements, and the influence of reactor insulation without requiring every operating condition to be experimentally repeated [8]. However, a critical limitation of many small-scale reactor assessments is the incomplete connection between numerical calculations and the geometry and construction of the fabricated reactor. When reactor dimensions, wall thickness, insulation characteristics, and boundary conditions are simplified or insufficiently reported, the resulting energy estimates can be difficult to reproduce or transfer to another experimental system [9]. This limitation is particularly important when the objective is to compare feedstocks using a common reactor platform.

A further challenge concerns the reproducibility and interpretation of legacy experimental datasets. Small-scale pyrolysis studies may report final oil volumes or selected temperature observations while omitting essential experimental metadata, such as heater power, thermocouple specifications and uncertainty, cooling-water flow rate, replicate number, or detailed feedstock characterization. Under such conditions, conventional experimental model validation cannot be performed rigorously because the primary measurements required to establish an independent energy balance are unavailable [10]. Treating incomplete observations as fully validated experimental data can therefore introduce an unwarranted level of certainty into the reported thermal performance [11]. A more defensible approach is to distinguish clearly between reported experimental observations, literature-derived thermophysical properties, model calculations, modelling assumptions, and previously generated numerical results [12].

These limitations identify a specific research gap: there is a need for a transparent and reproducible thermodynamic assessment framework that uses the reported geometry of a physically fabricated small-scale plastic pyrolysis reactor, explicitly separates feedstock and reactor thermal contributions, evaluates heat-loss sensitivity to insulation thickness, and provides a common energy basis for comparing reported oil production from different polyolefin feedstocks [13]. Addressing this gap is particularly relevant for PE, PP, and HDPE because their thermophysical and pyrolysis characteristics differ and therefore influence the total thermal requirement of the reactor. In addition, an energy-normalized indicator can provide a comparative screening measure when direct heater-energy measurements are unavailable, provided that it is explicitly distinguished from experimentally measured process efficiency [14].

Accordingly, this study develops a deterministic and reproducible thermodynamic model for a small-scale plastic pyrolysis reactor processing PE, PP, and HDPE waste [15]. The model is formulated from direct mass- and energy-balance relationships using the reported fabricated reactor geometry, literature-derived thermophysical properties, polymer fusion and pyrolysis enthalpies, reactor-wall heating, and heat-loss calculations [16]. The model is implemented in MATLAB to evaluate the thermal input requirement over 400–550 °C and to examine the sensitivity of the calculated energy requirement to

insulation thickness between 10 and 50 mm [17]. The calculated thermal requirements are then assessed alongside the reported plastic-waste-oil (PWO) volumes, and a reference energy-normalized oil-recovery index (REORI) is introduced as a comparative screening metric under a common reference condition [18]. Because the available legacy experimental records do not provide sufficient primary measurements for rigorous process-efficiency validation, the study deliberately avoids treating REORI as measured efficiency [19]. Instead, the contribution of this work is a reproducible thermal-engineering framework for transparent comparative assessment of small-scale plastic pyrolysis systems using incomplete but traceable experimental information [20].

The specific objectives of this study are therefore to: (i) quantify the thermal-energy requirements of PE, PP, and HDPE pyrolysis using a common small-scale reactor geometry; (ii) determine the influence of operating temperature and insulation thickness on the calculated thermal input; (iii) compare the reported PWO volumes on a common reference basis; and (iv) establish a reference energy-normalized indicator for comparative screening while explicitly identifying the limitations imposed by incomplete experimental records [21]. Through this approach, the study seeks to strengthen the connection between thermodynamic modelling, fabricated reactor design, and reproducible interpretation of legacy experimental data [22].

Recent research on plastic pyrolysis can broadly be grouped into three interconnected areas: feedstock and operating-condition studies, reactor and heat-transfer modelling, and thermodynamic or energy-based assessment. This thematic classification is important because the reported performance of a pyrolysis system is governed by interactions among polymer properties, operating conditions, reactor configuration, and thermal management rather than by temperature alone [23].

Previous experimental and review studies have established that the pyrolysis behaviour of polyolefins is strongly influenced by feedstock type, operating temperature, heating rate, residence time, particle size, vapour residence conditions, and reactor configuration [24]. PE and PP generally exhibit strong potential for liquid hydrocarbon production, while differences in polymer structure and thermal properties can alter the temperature range, degradation behaviour, and product distribution [25]. Increasing temperature can accelerate polymer-chain scission and volatile formation; however, excessive thermal severity may increase secondary cracking and shift products from condensable liquids toward permanent gases [26]. These studies provide an important basis for selecting operating conditions, but their primary emphasis is commonly on conversion behaviour and product distribution. Consequently, the thermal-energy penalty associated with heating the reactor hardware and compensating for external heat losses is not always evaluated on the same basis as product recovery.

A second group of studies has investigated reactor geometry, temperature distribution, heat transfer, residence time, and scale-up using finite-element, one-dimensional, and other heat-transfer models [27]. These approaches are valuable because pyrolysis is highly sensitive to heat-transfer limitations and the spatial distribution of temperature within the reaction system [28]. More detailed models can capture local thermal gradients and transport phenomena, whereas simplified models are computationally less demanding and can be more readily parameterized for engineering screening. However, the usefulness of such models depends strongly on the quality of the reactor geometry and boundary-condition data. When dimensions, wall thickness, insulation, heat-transfer coefficients, or operating boundaries are simplified or insufficiently documented, the resulting thermal predictions may be difficult to reproduce for a physically fabricated reactor [29]. Furthermore, numerically optimized dimensions or operating conditions do not necessarily correspond to the hardware that was actually manufactured and tested.

Thermodynamic approaches provide a complementary perspective by quantifying the energy required to heat the feedstock, overcome phase-change effects, drive pyrolysis reactions, and maintain the reactor at the required temperature [30]. Such models are particularly useful for comparing feedstocks and evaluating the influence of insulation and heat losses without requiring a complete experimental campaign for every design condition. However, a critical limitation is that the definition of the system boundary and the treatment of reactor thermal mass vary among studies. If only feedstock heating is considered, the calculated energy requirement may underestimate the thermal demand of a small-scale reactor with a relatively large metal mass. Conversely, the use of generalized heat-transfer coefficients or assumed heating efficiencies can introduce uncertainty when direct measurements are unavailable. Therefore, thermodynamic models should distinguish measured quantities from literature-derived properties and engineering assumptions, particularly when they are reconstructed from legacy experimental datasets.

A further issue concerns the reproducibility of small-scale pyrolysis assessments. Experimental studies can provide valuable observations of oil production and reactor temperature, but complete

energy-balance reconstruction requires additional information such as actual heater power or fuel consumption, thermocouple specifications and measurement uncertainty, cooling-water flow rate, replicate number, and sufficiently detailed feedstock characterization. When these records are unavailable, a conventional validation exercise based on independent measured energy inputs cannot be performed rigorously. The problem is compounded when reported experimental outputs coexist with separate numerical optimization results, because treating the latter as experimental observations can obscure the distinction between measured performance and model-derived results.

Taken together, the literature indicates that existing approaches provide strong capabilities in understanding feedstock degradation, product distribution, reactor heat transfer, and thermodynamic energy requirements, but these capabilities are often addressed separately. A remaining methodological gap is the lack of a transparent framework that simultaneously links a physically fabricated reactor geometry, feedstock-specific thermal requirements, reactor-wall thermal mass, heat-loss sensitivity, and reported oil production under a common reference basis. This gap becomes particularly important for small-scale systems, where reactor thermal mass and heat losses can represent a substantial fraction of the total thermal requirement.

The present study addresses this gap through a deterministic thermodynamic formulation based on the reported geometry of a fabricated stainless-steel pyrolysis reactor and a common 3 kg feedstock basis for PE, PP, and HDPE. The model explicitly separates the thermal contributions of the polymer feedstock, reactor wall, and heat loss, while evaluating the sensitivity of total thermal input to temperature and insulation thickness. A deterministic MATLAB implementation is used to ensure that the calculations can be reproduced from the stated equations and parameters. In addition, the reported PWO volumes are placed on a common reference-energy basis through the reference energy-normalized oil-recovery index (REORI). Importantly, REORI is treated only as a comparative screening metric rather than as experimentally measured process efficiency because the available source records do not contain sufficient direct heater-energy measurements for rigorous efficiency validation.

2. Literature Review

2.1. Recent Developments and Limitations in Plastic Pyrolysis Modelling

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3. Methodology

3.1. Experimental System and Reactor Configuration

The investigated system was a small-scale batch plastic pyrolysis unit consisting of a vertical cylindrical stainless-steel reactor connected to a reducer/damper, vapour pipe, separator, and water-cooled condenser. The reactor configuration and process flow were retained from the reported experimental apparatus, while the fabricated reactor geometry was treated as fixed hardware rather than as an optimization variable.

The reported reactor height was 0.517 m, with an inner diameter of 0.166 m and an outer diameter of 0.176 m. The vapour pipe had a reported length of 0.517 m and a diameter of 0.035 m. The experimental feedstock basis was 3 kg for each polymer type. The final reported PWO volumes were 1.50 L for PE, 1.40 L for HDPE, and 0.90 L for PP.

The reactor was represented in the thermodynamic model as a cylindrical shell with simplified end plates. Detailed flange, nozzle, support, and other auxiliary component masses were not included because their exact geometries were not sufficiently documented in the recovered experimental records. Accordingly, the calculated reactor mass represents a simplified thermal-mass approximation of the main reactor shell.

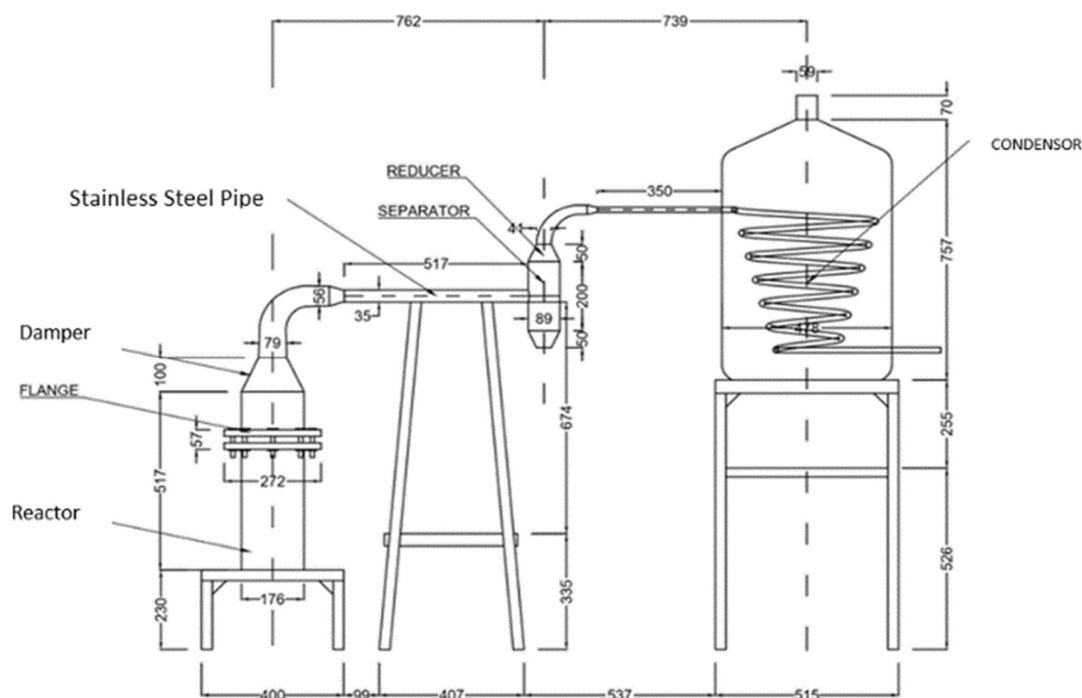


Figure 1. Engineering Drawing of the Fabricated Pyrolysis System

Figure 1 illustrates the engineering drawing of the fabricated pyrolysis system (reproduced from the source manuscript), while Figure 2 depicts the process schematic, highlighting the reactor, damper, vapour pipe, separator, and condenser.

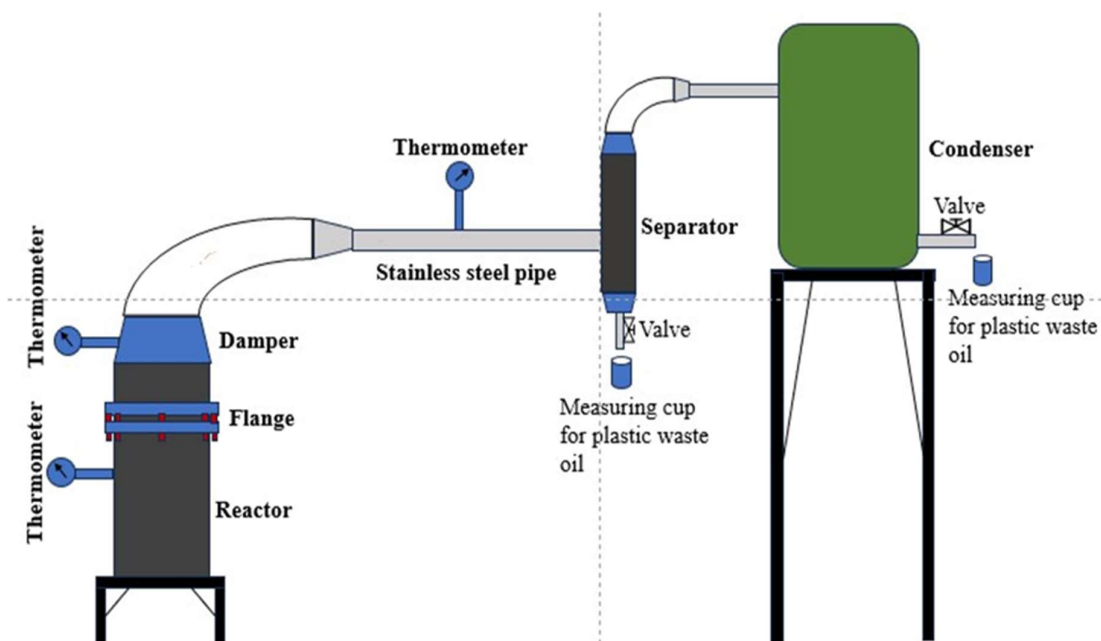


Figure 2. Process Schematic of the Pyrolysis System

Table 1. Reported Hardware and Experimental Quantities

Parameter	Reported Value	Use in revised Study
Reactor height	0.517 m	Fixed geometry
Reactor inner diameter	0.166 m	Fixed geometry
Reactor outer diameter	0.176 m	Fixed geometry
Vapour pipe length	0.517 m	Fixed geometry
Vapour pipe diameter	0.035 m	Fixed geometry
Experimental feedstock basis	3 kg per polymer (reported)	Model batch basis
Final PWO volume – PE	1500 mL	Reported observation
Final PWO volume – HDPE	1400 mL	Reported observation
Final PWO volume – PP	900 mL	Reported observation

3.2. Data Integrity and Modelling Boundary

The source manuscript contains a separate set of earlier numerical feedstock masses (7.03 kg PE, 6.80 kg PP, and 7.18 kg HDPE) and optimisation-derived temperatures and dimensions. Because those values belong to the legacy numerical optimisation rather than the reported experimental 3 kg trials, they are excluded from the present experimental normalization. No attempt is made to invent missing primary records such as thermocouple type, sensor uncertainty, heater power, cooling-water flow, or replicate count. Consequently, this paper is positioned as a thermodynamic modelling and experimental assessment study rather than a high-precision model-validation study.

The source document also contains an internal discrepancy between its time-series PWO plots and the larger summary totals reported in its comparison table. Because the underlying raw collection records are unavailable, the present analysis uses the summary-table totals only as reported summary observations and does not attempt to reconstruct a cumulative mass balance from the plotted curves. Any normalization or REORI calculation based on those summary totals therefore inherits this source-data limitation.

3.3. Thermophysical Properties and Engineering Assumptions

Polymer density, heat capacity, and thermal-conductivity values were taken from measured polyolefin data [13]. The exact grade of the material labelled PE in the source manuscript is not documented; therefore, it is retained as 'PE-reported' and is not silently relabelled as LDPE. Because repeated recycling can alter the property profile of polyolefins, grade and processing history remain relevant sources of uncertainty [14]. The HDPE fusion enthalpy and melting peak are taken from DSC measurements [10], whereas the PE and PP fusion enthalpies are explicitly treated as representative screening values rather than measurements from the source experiment. The PE and PP effective pyrolysis-heat values (390 and 660 kJ kg⁻¹) fall within experimentally reported reaction-heat ranges of 283.3-494.3 and 592.2-729.1 kJ kg⁻¹, respectively [15]. The HDPE heat of pyrolysis is set to 1375 kJ kg⁻¹ from isothermal DSC literature [16]. All grade-sensitive quantities should be varied if material-specific calorimetry becomes available.

Table 2. Baseline Assumptions Used in the Thermodynamic Model

Parameter	Baseline Value	Classification
Ambient temperature	25 ⁰ C	Assumed boundry Condition
Internal Heat- Transfer Coefisient	20 W m ⁻² K ⁻¹	Engineering assumption
External heat-transfer coefficient	8 W m ⁻² K ⁻¹	Engineering assumption
Insulation thermal conductivity	0.06 W m ⁻¹ K ⁻¹	Legacy modelling assumption
Insulation thickness	25 mm	Baseline sensitivity value
Stainless-steel density	7900 kg m ⁻³	AISI 304 literature surrogate

3.4. Reactor Geometry and Thermal Model

The reactor is represented as a cylindrical shell with two simplified end plates. The reactor internal volume is calculated from the internal diameter and height, while the stainless-steel mass is estimated from the difference between the outer and inner cylindrical volumes plus two end plates. This simplification intentionally excludes detailed flange, nozzle, and support masses because their exact geometries are not fully documented in the source file.

$$V_r = (\pi d_i^2 / 4) H \quad (1)$$

$$m_{steel} = \rho_{steel} [(\pi/4)(d_o^2 - d_i^2)H + 2(\pi d_o^2/4)t_{wall}] \quad (2)$$

The simplified shell mass calculated from the reported geometry is approximately 12.89 kg, with an external heat-transfer area of approximately 0.3345 m². The overall heat-transfer coefficient is calculated using one-dimensional thermal resistances through the internal film, steel wall, insulation layer, and external film:

$$1/U = 1/h_i + t_{wall}/k_{steel} + t_{ins}/k_{ins} + 1/h_o \quad (3)$$

For a model temperature T, the batch energy terms are:

$$Q_{feed} = m_f c_p (T - T_0) + m_f \Delta H_{fus} + m_f \Delta H_{py} \quad (4)$$

$$Q_{steel} = m_{steel} c_{p,steel} (T - T_0) \quad Q_{loss} = U A_{ext} (T - T_0) t \quad (5)$$

$$E_{input} = (Q_{feed} + Q_{steel} + Q_{loss}) / \eta_h \quad (6)$$

The formulation is deliberately deterministic and is evaluated directly from the governing thermodynamic equations. Temperature is swept from 400 to 550 °C in 10 °C increments. An insulation-thickness sensitivity analysis is performed from 10 to 50 mm at 500 °C. These numerical temperatures are modelling temperatures for thermodynamic screening and should not be confused with the lower temperatures recorded at specific measurement locations in the legacy experiment.

3.5. Reported Experimental Output and Mechanical Support Data

The source experiment reports final cumulative PWO volumes of 1500 mL for PE, 1400 mL for HDPE, and 900 mL for PP. Because replicate counts and uncertainty data are unavailable, no mean ± standard deviation or inferential statistical claims are generated. The source manuscript also reports heat-treated stainless-steel specimens followed by tensile testing at pretreatment temperatures from 100 to 400 °C. These material results are retained only as supporting evidence of the reactor-material study and are not used to calibrate the thermodynamic model.

3.6. MATLAB Implementation and Reproducibility

The numerical procedure is represented by a stand-alone MATLAB script supplied as supplementary material. The script defines the fixed geometry, assigns literature-derived thermophysical properties and explicitly labelled engineering assumptions, evaluates the energy terms for each feedstock and temperature, performs insulation sensitivity analysis, plots the reported PWO volumes, and exports CSV tables of calculated results. The code uses standard MATLAB numerical operations and does not require specialised optimisation toolboxes.

The editable supplementary file is named: 'pyrolysis_thermodynamic_model.m'.

4. Finding and Discussion

4.1. Thermal Energy Requirement as a Function of Model Temperature

The calculated thermal input increases monotonically with temperature for all three feedstocks (Figure 3). At the 500 °C baseline, the model predicts 10.67 MJ per 3 kg batch for PE-reported, 10.88 MJ for PP, and 14.00 MJ for HDPE. The higher HDPE value is driven primarily by the larger effective pyrolysis

enthalpy used from calorimetric literature [16], rather than by a higher sensible-heat term alone. At 400 °C the corresponding total inputs are 8.83, 9.19, and 12.28 MJ; at 550 °C they increase to 11.59, 11.72, and 14.86 MJ.

Figure 3 illustrates deterministic model predictions of total thermal input versus temperature for a 3-kg batch under baseline assumptions.

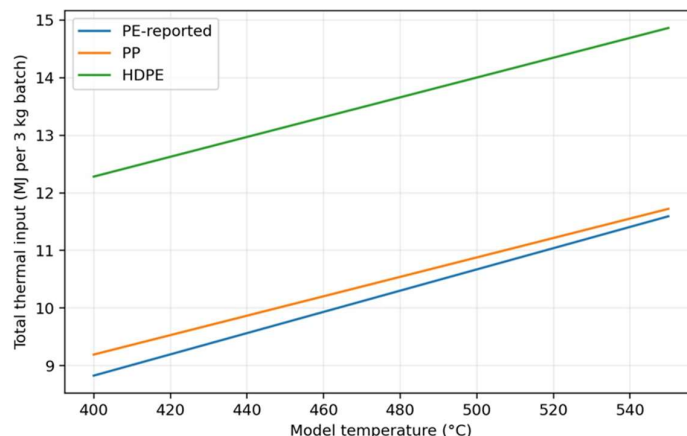


Figure 3. Predicted Thermal Input vs. Temperature for a 3 Kg Batch Under Baseline Assumptions

Table 3 shows selected deterministic model energy results for an assumed 25 mm insulation thickness and a 60-minute holding period.

Table 3. Selected Energy Results for 25 Mm Insulation Thickness and a 60-Minute Holding Period

Feedstock	Temperature (°C)	Feedstock Energy (MJ)	Reactor Energy (MJ)	Heat Loss (MJ)	Total Input (MJ)
PE-reported	400	3.88	2.42	0.76	8.83
PP	400	4.17	2.42	0.76	9.19
HDPE	400	6.65	2.42	0.76	12.28
PE-reported	450	4.19	2.74	0.86	9.75
PP	450	4.42	2.74	0.86	10.04
HDPE	450	6.91	2.74	0.86	13.14
PE-reported	500	4.51	3.06	0.97	10.67
PP	500	4.67	3.06	0.97	10.88
HDPE	500	7.17	3.06	0.97	14.00
PE-reported	550	4.82	3.38	1.07	11.59
PP	550	4.93	3.38	1.07	11.72
HDPE	550	7.44	3.38	1.07	14.86

The energy decomposition is useful because it prevents the model from attributing the complete thermal demand to the polymer reaction. For example, at 500 °C the simplified reactor-wall heating term is approximately 3.06 MJ for every feedstock because the same hardware is assumed, whereas the feedstock contribution differs with polymer properties. This finding reinforces the importance of reducing inactive thermal mass and improving insulation in small-scale systems, especially when the feedstock batch is small

4.2. Sensitivity to Assumed Insulation Thickness

Insulation thickness has a measurable influence on the calculated energy requirement (Figure 4). At 500 °C, increasing the assumed insulation thickness from 10 to 50 mm decreases total input from approximately 11.55 to 10.17 MJ for PE-reported, 11.76 to 10.38 MJ for PP, and 14.89 to 13.50 MJ for HDPE. These reductions correspond to approximately 12.0%, 11.7%, and 9.3%, respectively. The trend is physically expected because the thermal-resistance term increases as the insulation layer becomes thicker. However, because the actual insulation thickness in the original experiment is not documented, this result must be interpreted as design sensitivity rather than a measured efficiency improvement

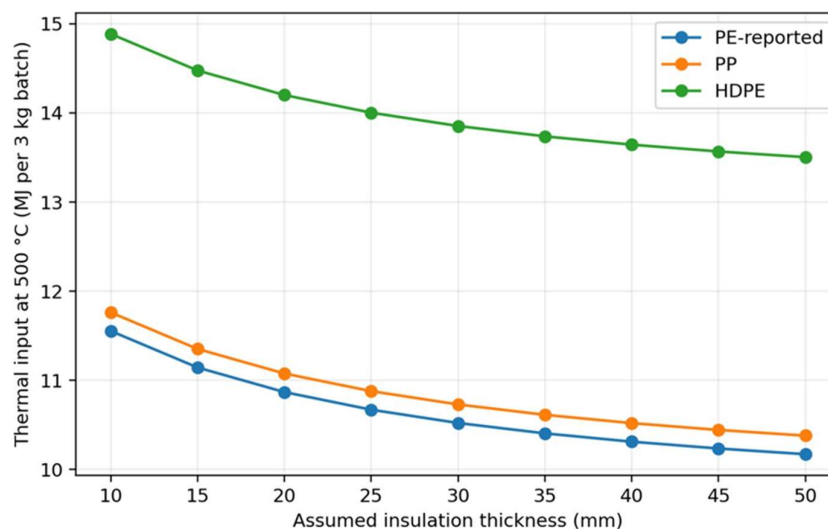


Figure 4. Sensitivity of Calculated 500 °C Thermal Input to Assumed Insulation Thickness

4.3. Reported PWO Production

The source summary-table PWO volumes are shown in Figure 5. The summary table reports 1.50 L for PE, 1.40 L for HDPE, and 0.90 L for PP. If the 3 kg charge stated in the experimental description is used only as a normalization basis, these values correspond to approximately 0.50, 0.47, and 0.30 L kg⁻¹, respectively. The time-series plots in the source document do not reconcile quantitatively with these larger summary values, and the raw collection records are unavailable. Accordingly, the present paper treats the values only as reported summary observations, does not convert them into mass yields, and does not claim carbon-balance closure.

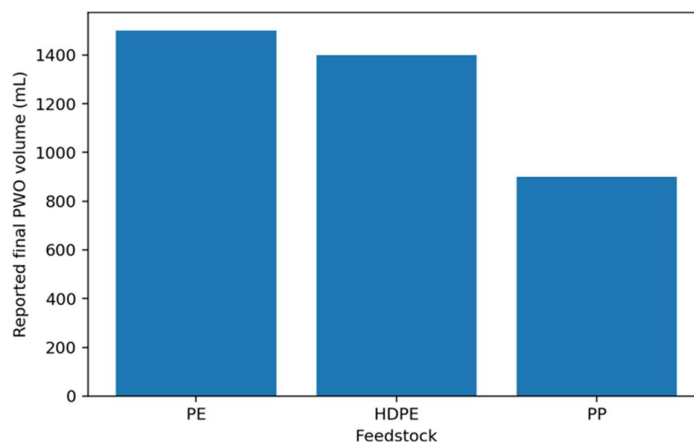


Figure 5. Reported Final Cumulative PWO Volume for the Three Feedstocks

Table 4 presents the reported pyrolytic wax oil (PWO) yield retained from the source experiment.

Table 4. Reported PWO Output from the Source Experiment

Feedstock	Reported Final PWO (mL)	Reported-Volume Basis (L kg ⁻¹ , Assuming 3 kg Charge)
PE	1500	0.5
HDPE	1400	0.47
PP	900	0.3

The reported ranking differs from the legacy numerical optimisation results in the source manuscript, which predicted higher yields for PP and HDPE. This disagreement is not hidden or reconciled by relabelling one dataset. Instead, the revised paper treats the legacy optimisation output and the actual reported PWO observations as distinct datasets. Such separation is essential because numerical predictions and experimental yields can differ due to temperature gradients, vapour losses, condensation efficiency, feedstock preparation, and measurement location.

4.4. Interpretation of Reported Temperature Data

The source manuscript reports monitored reactor temperatures of approximately 300 °C for PE, 225 °C for HDPE, and 295 °C for PP at the ending condition. These readings are substantially below the 400-550 °C modelling window commonly used for thermal pyrolysis of polyolefins. The revised manuscript therefore does not interpret the reported sensor value as the true polymer reaction-zone temperature. A more defensible interpretation is that the temperature corresponds to the monitored location on or near the reactor assembly. Temperature gradients between the heated wall, polymer bed, vapour space, and external sensor position can be large in small batch reactors. This issue should be resolved in future work with calibrated thermocouples placed directly in the reaction zone.

4.5. Stainless-Steel Mechanical Observations

The reported tensile-test results after different thermal exposures are summarized in Figure 6 and Table 5. Yield stress increased from 215.87 MPa after the 100 °C treatment to 357.14 MPa after the 400 °C treatment, whereas ultimate tensile stress varied non-monotonically between 390.92 and 544.28 MPa. Because the source material grade, heat-treatment protocol, weld geometry, and replicate statistics are incomplete, these data should be interpreted as supporting observations rather than a full elevated-temperature material qualification. Nevertheless, they document that the original reactor study included a mechanical-material component in addition to process measurements.

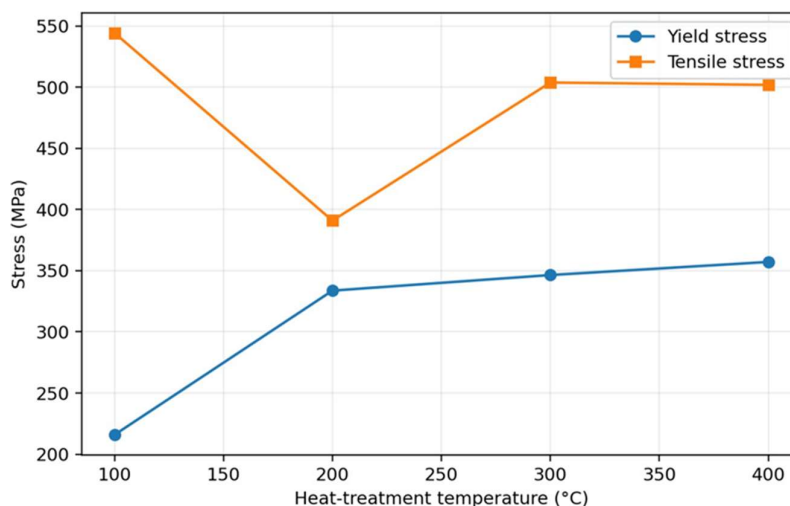


Figure 6. Yield and Tensile Stresses of Thermal-Exposed Stainless-Steel Specimens

Table 5. Energy-Normalized Oil Recovery Screening Under Common Model Conditions

Feedstock	Reported PWO (L)	Model input at 500 °C (MJ)	REORI (L/MJ)
PE	1.5	10.67	0.141
HDPE	1.4	14	0.1
PP	0.9	10.88	0.083

4.6. Engineering Implications and Study Limitations

The reconstructed analysis produces three engineering insights. First, hardware thermal mass is a substantial component of the total batch energy, so small-scale reactors benefit from high feedstock-to-reactor mass ratios and improved insulation. Second, the reported PWO outputs clearly depend on feedstock, but the available data do not justify a mechanistic claim based solely on final volume. Third, the discrepancy between monitored temperatures and typical polyolefin pyrolysis temperatures demonstrates why sensor placement and calibration must be treated as critical experimental variables rather than incidental details.

The principal limitation is the absence of complete primary experimental records. The revised study does not fabricate these data. Specifically, heater power or fuel consumption, thermocouple model and accuracy, cooling-water flow, exact PE grade, replicate number, and raw oil-density measurements are unavailable. Accordingly, the numerical energy values should be read as transparent design-screening calculations rather than measured process energy. The supplied MATLAB code is intentionally parameterized so that these assumptions can be replaced immediately if original laboratory values later become available.

5. Conclusions

A deterministic MATLAB thermodynamic model was developed for the reported small-scale PE, PP, and HDPE pyrolysis reactor using direct mass- and energy-balance calculations. Using the reported 3 kg batch basis and fixed reactor geometry, the baseline model predicts thermal inputs at 500 °C of 10.67 MJ for PE-reported, 10.88 MJ for PP, and 14.00 MJ for HDPE. Increasing the assumed insulation thickness from 10 to 50 mm reduces the calculated energy requirement by approximately 9-12%, demonstrating the importance of thermal resistance in small-batch reactor design. The source experiment reports final cumulative PWO volumes of 1.50 L for PE, 1.40 L for HDPE, and 0.90 L for PP. Under the common 500 °C reference model condition, the study-specific REORI values are 0.141, 0.100, and 0.083 L/MJ for PE, HDPE, and PP, respectively. These values are comparative screening indicators rather than measured efficiencies. Experimental observations are kept separate from literature-derived properties, modelling assumptions, and legacy numerical predictions. The principal contribution is a reproducible thermal-engineering framework that integrates fixed hardware geometry, energy decomposition, insulation sensitivity, standardized energy-normalized oil-recovery screening, and explicit data provenance. Future work should measure actual heater energy, calibrated reaction-zone temperature, oil mass yield, condenser heat removal, and replicate variability to enable rigorous process-efficiency validation.

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