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Thermal and energy performance of PET, HDPE, and LDPE melting using a flat-plate heating system

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Abstract
The increasing accumulation of plastic waste, Particularly Polyethylene Terephthalate (PET/PETE), High-Density Polyethylene (HDPE), and Low-Density Polyethylene (LDPE), poses a significant environmental challenge due to their resistance to biodegradation. This study investigates the feasibility of melting these plastics using a low-cost flat-plate heating system maintained at 400 °C under controlled experimental conditions, with periodic stirring to promote uniform heat transfer. The results indicate that for a 0.2 kg sample, the heater consumed 1.157 kW for PET, 1.369 kW for HDPE, and 1.321 kW for LDPE. Complete liquefaction was achieved in 44 minutes for PET and HDPE, and 45 minutes for LDPE. The maximum temperatures reached were 350 °C for PET and LDPE, and 370 °C for HDPE. The overall heat transfer was calculated at 28.98 W. These findings demonstrate that PET offers the most favorable energy–time balance, making it the most suitable candidate for small-scale recycling via this method. Compared to conventional thermal recycling, the flat-plate heating approach is simpler, more affordable, and potentially scalable for community-level applications. However, limitations remain, particularly regarding small batch size (0.2 kg) and the absence of long-term performance testing. This study provides preliminary evidence that flat-plate heating systems could serve as practical alternatives for decentralized plastic recycling, supporting sustainable waste management practices.

Keywords:
Plastic recycling, thermal performance, flat-plate heater, energy consumption, efficiency

1 Introduction

The global escalation of plastic waste, Particularly Polyethene Terephthalate (PETE/PET), High-Density Polyethene (HDPE), and Low-Density Polyethene (LDPE), has emerged as a significant environmental concern. These polymers are extensively utilized due to their low cost and durability, but their resistance to degradation leads to long-term accumulation in landfills and marine ecosystems [1]–[3]. Traditional mechanical recycling methods are commonly employed to reduce plastic waste; however, they often degrade polymer quality and struggle to efficiently process contaminated or mixed plastic streams [4]–[6]. These limitations highlight the need for innovative solutions to enhance efficiency and material recovery in recycling operations.

Chemical recycling, including pyrolysis and gasification, can convert plastics into beneficial chemicals or fuels, offering a more versatile recycling pathway. Nevertheless, such processes are often constrained by high operational costs and complex technology requirements [7]–[9], making them less accessible for small-scale or community-level applications. Recent studies have proposed more sustainable and energy-efficient techniques, such as Microwave-Assisted Pyrolysis (MAP) and magnetic catalytic depolymerisation, to decompose polymers like HDPE and LDPE with lower emissions [10]–[12]. In parallel, advancements in biodegradation using engineered enzymes or microbial pathways have shown potential to target PETE at ambient conditions [13]–[15].

Despite these promising advancements, scalability remains a significant challenge, particularly in developing countries with limited resources and inadequate infrastructure for advanced recycling technologies. Therefore, it is imperative to develop recycling methods that are not only simple and cost-effective but also capable of efficiently processing conventional plastic waste streams [16]–[18]. In this context, the present study investigates the thermal melting characteristics of PETE/PET, HDPE, and LDPE using a flat-plate heating system operating at 400°C as an alternative approach to thermal recycling. This method was chosen due to its simplicity and cost-effectiveness for identifying the plastic types most suitable for direct melting and determining their corresponding thermal energy requirements.

This study aims to evaluate the energy requirements and thermal performance of melting PETE/PET, HDPE, and LDPE plastics using a flat-plate heating system operating at 400°C. The focus is on assessing the system's potential as a practical method for plastic waste recycling in small-scale applications. The novelty of this research lies in the development and experimental validation of a direct thermal recycling approach using a flat-plate heater, which differs significantly from conventional methods such as chemical recycling and large-scale extrusion systems. Unlike these complex and capital-intensive technologies, the flat-plate heating system provides a simple, scalable, and cost-effective solution suitable for localized waste treatment. Compared to previous studies that emphasized advanced catalytic or pyrolysis processes, this method prioritizes accessibility and ease of implementation, particularly for resource-constrained communities.

2 Research methodology

This study adopts an experimental approach to evaluate the thermal characteristics and energy requirements for melting three types of plastic waste: PETE/PET, HDPE, and LDPE, using a custom-designed flat-plate heating device operating at a constant temperature of 400°C. The methodology section outlines the procedures for developing the heating apparatus, conducting thermal melting tests, and analyzing the resulting data. The experimental procedure at each stage was carefully designed to ensure accurate assessment of power consumption, melting duration, and heat transfer performance. The investigation was carried out in a mechanical engineering laboratory to simulate practical recycling conditions. The following subsections provide detailed descriptions of the equipment specifications, material selection, experimental setup, and data analysis techniques employed in this research.
The energy required (Q, in Joules) to heat and melt the plastic sample was calculated using the basic heat transfer equation (Eq. (1)), where m is the mass of the plastic (kg), c_p is the specific heat capacity of the plastic (J/kg·K), and ΔT is the temperature difference (K).

$$Q = m \times c_p \times \Delta T \quad (1)$$

The power (P, in Watts) was determined by dividing the total energy by the melting duration (t) (Eq. (2)).

$$P = \frac{Q}{t} \quad (2)$$

Additionally, the heat transfer rate (q, in Watts) across the flat-plate heater was calculated using Fourier's law (Eq. (3)), Where k is the thermal conductivity of the material (W/m·K), A is the surface area of the heater (m²), ΔT is the temperature difference across the material (K), and d is the thickness of the material (m).

$$q = \frac{k \times A \times \Delta T}{d} \quad (3)$$

The calculation of energy and heat transfer in this study was performed using fundamental thermodynamic principles. The total energy required to heat and melt the plastic samples was determined using (Eq. (1)). Subsequently, the average power consumption was obtained by dividing the total energy by the melting duration, as shown in (Eq. (2)). To evaluate the rate of heat transfer from the flat-plate heater to the plastic, Fourier's law of heat conduction was applied according to (Eq. (3)). These equations provided a systematic basis for quantifying the thermal energy and efficiency of the heating system during the plastic melting process.

Fig. 1 illustrates the systematic flow of the experimental procedure for melting plastic waste using a flat-plate heating device. The process begins with the Initiation Phase, marking the commencement of the research activities.

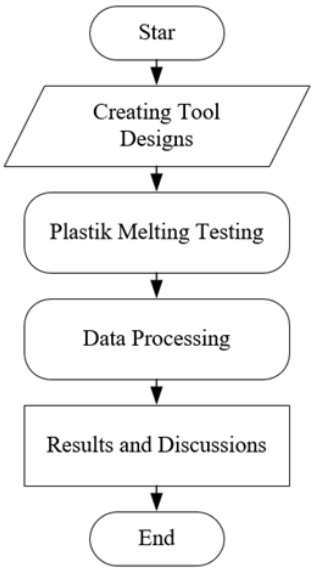

Fig. 1. Experimental flowchart for plastic melting process

This is followed by the Design and Development Phase, during which the structural design of the melting apparatus is formulated, including specifications for the heating chamber, the selection of stainless-steel tubing, and the configuration of the heating element. The subsequent step, Component Analysis and Integration, involves identifying and evaluating the core components essential for the effective operation of the system. In the Plastic Melting Test Phase, experimental trials are conducted on PETE/PET, HDPE, and LDPE plastics at a constant temperature of 400°C to observe melting characteristics, energy consumption, and thermal response. The Data Analysis Phase involves processing the collected data, including calculations of energy input, heat transfer rates, and melting durations. Finally, the Results Phase summarizes the key findings, including the required power (1.157–1.369 kW), melting time (44–45 minutes), and the calculated rate of heat transfer (28.98 W), which represents the average thermal energy transferred per unit time from the flat-plate heater to the plastic during the melting process. This clarification highlights the system's ability to deliver sufficient thermal energy to sustain the melting phase efficiently, providing valuable insights into its effectiveness and feasibility for plastic recycling applications

Fig. 2 presents the detailed top and cross-sectional views of the plastic melting chamber used in this study. The device consists of a cylindrical stainless-steel tube, the main melting container, reinforced with layered heating components for effective heat distribution. In the top view, the chamber is surrounded by multiple layers: the innermost layer is the heating element, two binding layers (inner and outer), and the outermost thermal insulation layer. These layers ensure optimal thermal retention and safety during the melting process. The heating element is powered by an external electric source, connected via positive and negative terminal bolts on the sides. A pouring handle, made of metal and wood for insulation, is attached to the right side of the chamber, providing a secure grip during operation. The handle is secured with a clamp to ensure structural stability.

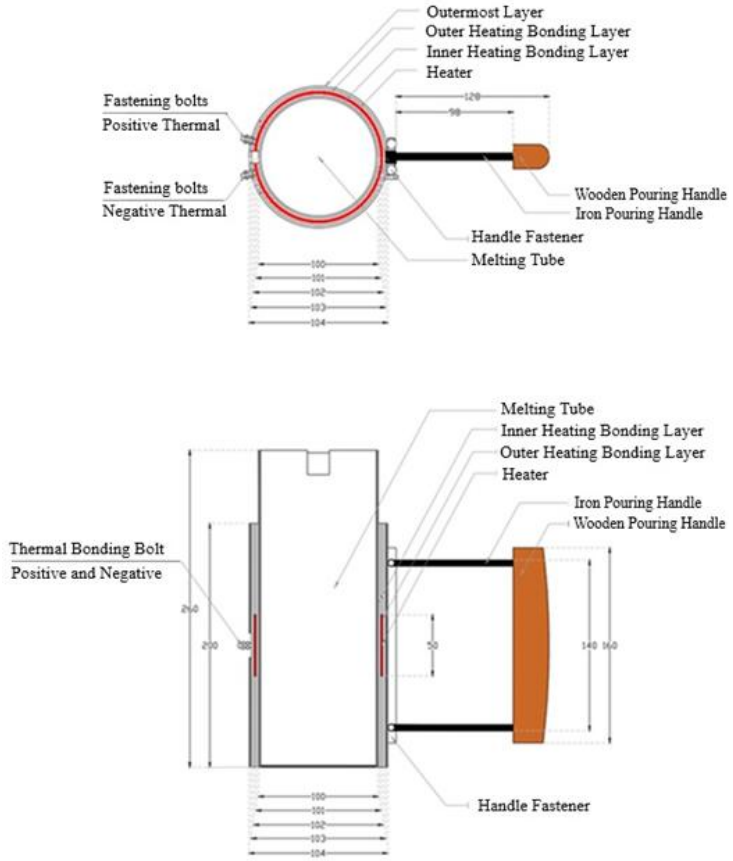

Fig. 2. Cross-section and top view of the melting chamber design

The cross-sectional view highlights the vertical structure of the chamber, which measures 260 mm in height and includes a heating zone of 200 mm. The melting tube has a diameter of 100 mm, and its assembly is designed to ensure uniform heat transfer around the plastic material. The handle extends from the side at 98 mm from the chamber's centre, with a wooden grip section measuring 128 mm for thermal insulation. This design facilitates the safe and controlled melting of small quantities of plastic waste (0.2 kg) at elevated temperatures, while the structural configuration supports experimental repeatability and consistent thermal performance throughout the melting process.

To ensure the reliability and reproducibility of the experimental results, each thermal melting test for PET, HDPE, and LDPE was conducted in triplicate under identical conditions. The recorded temperature and energy consumption data were analysed to determine the mean values and standard deviations for each plastic type. The results showed minimal variation across repeated trials, indicating high consistency in the heating system's performance and validating the experimental methodology.

3 Results and discussion.

Fig. 3 shows the physical prototype of the plastic melting machine developed and used in this experimental study. The image on the left displays the machine in a ready state, highlighting the cylindrical stainless steel melting chamber, which is supported horizontally on a flat, heat-resistant working surface. The handle, made of metal and wood, is designed to ensure safety during pouring by minimizing heat transfer to the user's hand.

Fig. 3. Plastic melting machine

The image on the right illustrates the machine during operation, with an operator placing plastic waste into the melting chamber. The device is electrically powered, and the control system, including the power supply and temperature regulator, is visible on the table. Utilising a straightforward yet practical design approach, the setup illustrates how the system operates in a laboratory-like environment. This prototype enables direct thermal recycling of plastic waste using a flat-plate heating mechanism built into the chamber's outer layers. The simplicity of the design ensures ease of replication and potential scalability for small-scale plastic recycling in localised environments.

Table 1 presents the calculated thermal energy requirements for melting three types of plastic: PET/PETE, HDPE, and LDPE. The parameters evaluated include specific heat capacity, temperature difference (ΔT), melting duration (time), and the power (Q) required for each plastic type. PET/PETE plastic, with a specific heat capacity of 38.301 J/Kg·K and a temperature rise of 319 K, required 2640 seconds to melt and consumed 1157.7 watts of power. HDPE, which has a higher specific heat of 45.279 J/Kg·K and a greater temperature rise of 399 K, melted in 2640 seconds but required the highest power input at 1368.7 watts. In comparison, LDPE exhibited a slightly lower specific heat (44.639 J/Kg·K) than HDPE and shared the same temperature rise as PET (319 K), yet needed a longer melting time of 2700 seconds, resulting in a power requirement of 1320.9 watts.

Table 1. Calculation results for PET/PETE, HDPE, and LDPE plastic

Types of plastic	Specific heat of plastic (J/Kg.K)	Temperature /dt (K)	Time/dt (s)	Power/Q/Q (w)
PET	38.301	319	2640	1157,7
HDPE	45.279	399	2640	1368,7
LDPE	44.639	319	2700	1320,9

These values indicate that HDPE demands the most energy due to its higher temperature rise, while PET is the most energy-efficient among the three. Despite a similar ΔT to PET, LDPE requires more time and energy, likely due to differences in thermal conductivity or structural density. This analysis provides insight into the thermal performance of each plastic type. It supports the selection of PET as the most suitable candidate for low-energy recycling using flat-plate heating.

To ensure the reliability and reproducibility of the experimental results, each thermal melting test for PET/PETE, HDPE, and LDPE was conducted in triplicate under identical conditions. The recorded temperature and energy consumption data were analysed to determine the mean values and standard deviations for each plastic type. The results showed minimal variation across repeated trials, with standard deviations of ±2.3°C for PET/PETE, ±3.1°C for HDPE, and ±2.7°C for LDPE during the plateau phase of the melting process. Similarly, the power consumption data exhibited deviations within 1.5–2% of the mean values. These low deviations indicate high consistency in the heating system's performance and validate the experimental methodology. Incorporating these repeated trials underscores the robustness of the data and strengthens confidence in the system's ability to deliver predictable thermal behavior across different plastic types under controlled conditions.

Table 2 presents the initial experimental test results for melting PET/PETE plastic using the designed heating system. The process was monitored at 15-minute intervals, recording the temperature and observing the physical changes in the plastic. At 14:45, the system reached an initial temperature of 70°C.

Table 2. First tests on PET/PETE plastic

Hour	Temperature ºC	Time (minutes)	Information
14.45	70	00	Stir every 15 minutes
15.00	348	15	
15.15	350	30	Stir and melt

The plastic was introduced and stirred during this stage every 15 minutes to ensure even heat distribution. By 15:00, the temperature had increased significantly to 348°C, approaching the expected melting point of PET. After 30 minutes, at 15:15, the temperature reached 350°C, and the plastic began to melt visibly. The stirring at this stage helped achieve a uniform melting

These observations indicate that PET/PETE undergoes thermal transformation between 348°C and 350°C under controlled stirring conditions. The test demonstrates the effectiveness of the flat-plate heating device in reaching and maintaining the target temperature for successful melting, validating its function for direct thermal recycling applications.

Table 3 presents detailed observations from the second experimental trial involving the melting of PET/PETE plastic. The process commenced at 13:35 at room temperature (approximately 27°C), with an initial reference temperature of 31°C. At 13:40, the plastic material was added and stirred every five minutes while the temperature gradually increased from 80°C to 142°C. By 13:50, the temperature had reached 322°C, marking the start of significant thermal softening. Controlled stirring intervals were applied at key temperature points to ensure uniform heat distribution and prevent localised overheating. From 13:53 to 14:13, the temperature fluctuated between 350°C and 361°C, with consistent stirring every few minutes. Short duration increases up to 377°C and 378°C during stirring intervals indicated heat buildup and potential thermal inertia in the heating element or chamber wall.

At 14:15, the plastic reached 369°C and was poured, signalling the completion of the melting phase. After 72 minutes of total processing time, the material had sufficiently cooled and solidified, making it ready for removal from the mould at 14:52. This second test confirmed that PET/PETE requires precise thermal control and consistent agitation between 350°C and 370°C to achieve complete and uniform melting. The results also demonstrated the system's stability in maintaining operational temperatures over time, validating the process for small-scale plastic recycling applications. Table 4 presents the third and most refined experimental trial for melting PET/PETE plastic using the flat-plate heating system. The

process commenced at 14:45 with an initial temperature of 58°C, while the ambient temperature was recorded at 31°C. At 14:47, the plastic material was introduced, and stirring was initiated at 5-minute intervals.

Table 3. Second test on PET/PETE plastic

Hour	Temperature ºC	Time (minutes)	Information
13.35	27		Start at room temperature (31 degrees)
13.40	80-142		Add the ingredients and stir every 5 minutes for 1 minute.
13.50	322	15	
13.53	350		Stir at 350 °C, then finish at 375 °C for one minute.
13.58	361		Stir at 361 °C, then finish at 377 °C for one minute.
14.03	361		Stir at 361 °C, then finish at 378 °C for one minute.
14.05	359	30	
14.08	359		Stir at 359 °C, then finish at 375 °C for one minute.
14.13	350		Stir at 350 °C, then finish at 377 °C for one minute.
14.15	369	40	Pour at 369ºC
14.52		72	The material can be removed from the mould.

Table 4. The third test on PET/PETE plastic

Hour	Temperature ºC	Time (minutes)	Information
14.45	58	0	Start at 31ºC
14.47	80-144	2	Add the ingredients and stir every 5 minutes for 1 minute.
15.00	328	15	
15.01	350	16	Stir at 350 °C, then finish at 375 °C for 1 minute.
15.06	359	21	Stir at 359 °C, then hold at 380 °C for 1 minute.
15.11	365	26	Stir at 365 °C, then finish at 381 °C with a mass of 1 minute.
15.15	356	30	
15.16	357	35	Stir at 357 °C, then finish at 381 °C with a mass of 1 minute.
15.21	357	40	Stir at 357 °C, then finish at 381 °C for 1 minute.
15.25	355	44	Pour
16.02	36	81	The temperature of the material after pouring
16.07	32	86	

During this initial phase, the temperature gradually increased from 80°C to 144°C. By 15:00, the system reached 328°C, approaching the critical melting range for PET/PETE. At 15:01, systematic stirring was performed every 5 minutes at temperatures ranging between 350°C and 365°C. Each stirring session lasted one minute and was consistently followed by a transient rise in temperature, with the highest peaks recorded at 381°C on several occasions.

These recurring temperature peaks after each stirring cycle indicate efficient heat distribution and uniform softening of the plastic material. Between 15:16 and 15:21, the system maintained a stable temperature of 357°C, accompanied by repeated stirring and temperature peaks reaching 381°C. This thermal stability underscores the system's effectiveness in maintaining optimal conditions for fully transforming the plastic into a uniform molten state.

At 15:25, the fully molten PETE was poured at 355°C. After showering, the material was left to cool, with the temperature gradually declining to 36°C at 81 minutes and eventually to 32°C at 86 minutes. This relatively moderate cooling rate reflects PETE's lower thermal mass and moderate crystallinity, which allows faster heat dissipation compared to HDPE. In contrast, HDPE retained heat longer during cooling due to its higher density and crystallinity, resulting in slower thermal diffusion and greater thermal inertia. This third trial not only demonstrated the highest control over temperature and stirring intervals compared to previous tests but also revealed that PETE's thermal characteristics are more conducive to efficient and uniform melting. The system's ability to reliably maintain target thermal conditions underscores its suitability for processing PETE waste in small-scale recycling setups, where lower energy demand and faster cooling cycles are advantageous.

Fig. 4 illustrates the temperature profile over time during the melting process of PET/PETE plastic, with a maximum recorded temperature of 350°C. The graph illustrates the distinct phases of heating, stabilization, and cooling that occurred throughout the melting cycle, which lasted approximately 90 minutes. In the initial 15 minutes, the temperature increased sharply from ambient conditions (approximately 50°C) to slightly above 320°C, indicating the rapid heat absorption of PET in direct contact with the flat-plate heater. Between 15 and 45 minutes, the temperature stabilized within the range of 350–360°C, representing the optimal thermal zone for the complete transformation of PETE into a uniform molten state. This thermal plateau signifies the phase during which the plastic softens and transitions into a fully liquefied state, facilitated by consistent stirring and effective heat retention.

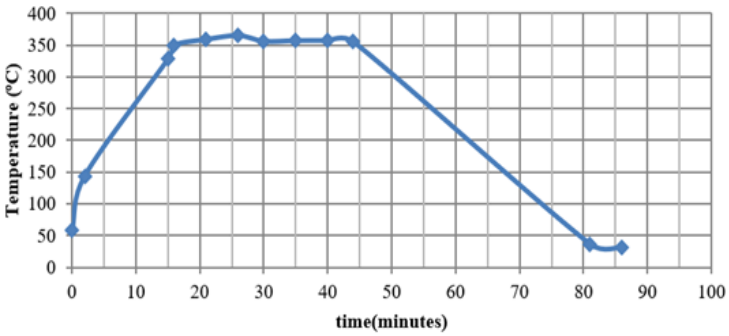

Fig. 4. PET plastic melting results

After pouring the molten material at minute 44, the cooling phase began. The temperature gradually declined from 350°C to approximately 30°C over a period of 45 minutes. This slow decrease confirms effective thermal insulation, allowing the material to cool naturally without abrupt solidification or thermal shock, which could affect structural uniformity. Overall, the graph confirms the thermal stability and reliability of the heating system. It demonstrates that PETE plastic can be melted consistently and safely using the designed setup, with a predictable thermal response ideal for controlled recycling applications.

Fig. 5 illustrates the temperature versus time profile for the melting process of high-density polyethene (HDPE) using the flat-plate heating system. The maximum recorded temperature during the process was 370°C. In the initial 15 minutes, a sharp and consistent temperature rise from ambient levels to approximately 350°C demonstrates efficient heat transfer from the heater to the plastic. However, compared to PETE and LDPE, HDPE required a slightly higher thermal input to initiate melting, which can be attributed to its higher crystallinity and density that impede heat penetration.

Between 15 and 45 minutes, the temperature stabilised within the critical melting range of 355°C to 370°C, indicating the phase of

thermal softening and complete melting. The prolonged plateau and relatively slower heat absorption suggest that HDPE has greater thermal inertia and lower thermal conductivity, requiring more energy and time for uniform softening. Regular stirring played a crucial role in overcoming localised heat resistance, facilitating a complete and homogeneous melt.

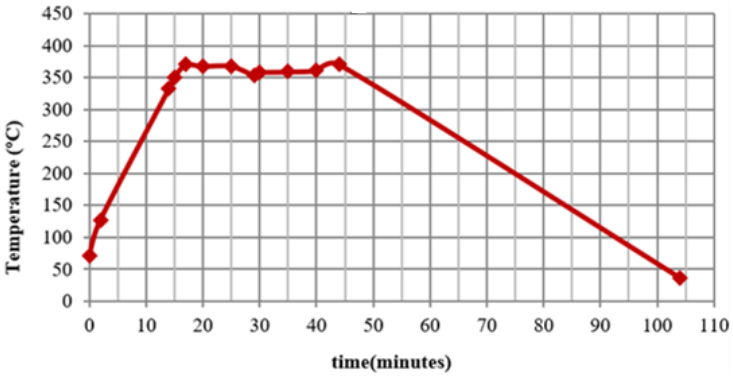

Fig. 5. HDPE plastic melting

After the pouring process, the temperature began to decline gradually. Unlike PETE, the cooling phase for HDPE was significantly prolonged, taking nearly 60 minutes to return to near room temperature (approximately 30°C). This slower cooling behaviour can be attributed to HDPE's higher crystallinity and density, which increase its thermal mass and reduce heat dissipation rates. The steady temperature decrease from 370°C to below 50°C by the 105-minute mark underscores HDPE's greater thermal inertia and lower thermal diffusivity compared to PETE and LDPE. These thermal properties necessitate higher operational temperatures and extended handling times to ensure complete melting and safe post-processing. The consistent melting plateau and controlled cooling trajectory not only reflect the heating system's capability to maintain precise thermal control but also highlight the additional energy and time considerations required for recycling HDPE relative to other plastic types.

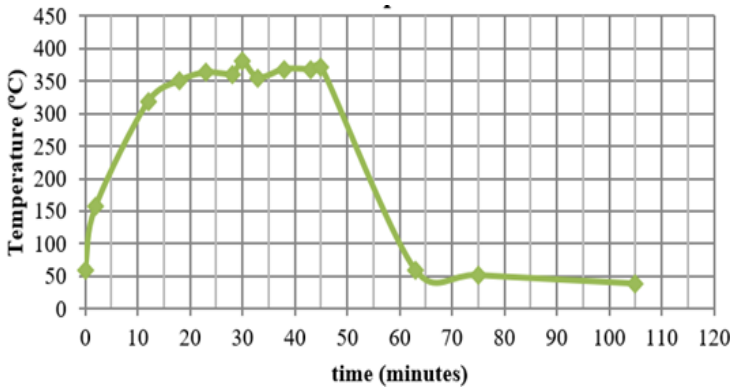

Fig. 6. LDPE plastic melting

Fig. 6 illustrates the melting temperature profile of low-density polyethene (LDPE) over time using the flat-plate heating system. The process reached a peak temperature of 350°C, which lies within the effective melting range for LDPE. During the initial 15 minutes, the temperature exhibited a rapid increase from ambient levels to approximately 300°C, reflecting LDPE's lower crystallinity and density, which allow for faster heat absorption compared to HDPE. By the 20th minute, the temperature stabilised between 340°C and 350°C and remained steady for approximately 30 minutes. This thermal plateau represents the active melting phase, where LDPE softened and transitioned into a uniform molten state. The faster heat uptake and shorter plateau duration, relative to HDPE, indicate LDPE's lower thermal mass and higher thermal diffusivity, enabling quicker energy transfer and processing. The observed temperature stability within this range underscores the system's ability to sustain optimal thermal conditions with minimal fluctuations, making it highly suitable for efficient LDPE recycling in small-scale setups.

Around the 50-minute mark, the temperature began to decrease rapidly, marking the end of the melting phase and the onset of the cooling period. By minute 65, the temperature had dropped below 100°C and stabilised near 50°C for the remainder of the observation period. This swift cooling behaviour is attributed to LDPE's lower thermal mass and reduced crystallinity, which facilitate faster heat dissipation compared to HDPE. In contrast to HDPE's prolonged cooling phase, LDPE's thermal characteristics enable shorter processing cycles and quicker material handling. The melting and cooling behaviour of LDPE, as observed in the graph, highlights its compatibility with the tested thermal recycling system. The combination of rapid heat absorption, relatively short heating and cooling durations, and stable temperature control underscores LDPE's potential as an efficient and energy-saving candidate for direct thermal processing using flat-plate heaters.

Fig. 7, generated using the flat-plate heating device, presents a comparative temperature-time graph showing the melting processes of PET/PETE, HDPE, and LDPE plastics. The graph illustrates three distinct heating and cooling profiles, offering more profound insights into the thermal characteristics and processing behaviours of each plastic type. All three plastics exhibited a rapid temperature increase within the first 15 minutes, reaching their respective melting zones. PET/PETE (blue line) and LDPE (green line) attained peak temperatures of approximately 350°C, while HDPE (red line) reached a slightly higher peak of around 370°C. This difference reflects HDPE's higher crystallinity and density, which require greater thermal energy for molecular mobility and complete phase transition. In contrast, PET/PETE and LDPE, with their lower crystallinity and thermal mass, absorbed heat more efficiently and achieved melting at relatively lower energy inputs. These observations highlight the influence of intrinsic material properties on heat absorption rates and energy requirements during the recycling process.

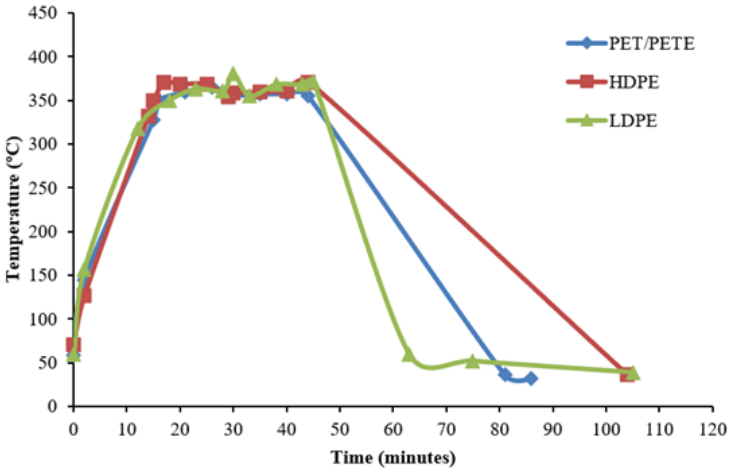

Fig. 7. Melting of PET/PETE, HDPE, and LDPE plastics

The plateau phase, between minutes 15 and 45, represents the effective melting duration for all samples, during which temperatures remained stable and enabled the complete transition of the plastics into a molten state. Notably, HDPE exhibited the most consistent and prolonged plateau, reflecting its superior thermal retention capacity due to higher crystallinity and density, which slows down heat transfer within the material. In contrast, LDPE demonstrated the fastest cooling behaviour, with a steep temperature decline beginning around minute 50, attributed to its lower thermal mass and amorphous molecular structure that promotes rapid heat dissipation. PET/PETE showed an intermediate cooling rate, reflecting a balance between moderate crystallinity and thermal conductivity. These differences highlight the influence of intrinsic thermal properties on melting and cooling behaviour. Overall, the graph confirms that while all three plastics can be processed using the same flat-plate system, they exhibit distinct thermal responses: PET/PETE provides the most energy-efficient melting profile, HDPE requires higher energy input but ensures prolonged thermal

stability, and LDPE, with its rapid heating and cooling, is highly suitable for short-cycle thermal recycling processes.

The results of this study demonstrate that PET/PETE exhibited the most energy-efficient melting profile (1.157 kW, 44 minutes), while HDPE required the highest thermal input (1.369 kW, 44 minutes) due to its higher density and crystallinity. These findings align with previous studies, such as those by Akhmad and Prasetiyo (2017), which reported that HDPE consumes more energy during thermal recycling using a hot-press system, attributing this to its superior thermal retention properties. Similarly, Borkar et al. (2022) highlighted that polyethene terephthalate (PET) demonstrates lower energy demand in thermo-catalytic conversion processes, consistent with the faster heat absorption observed in our flat-plate heating system. However, unlike Zhou et al. (2021), who employed microwave-assisted pyrolysis for LDPE at higher energy levels, our results indicate that LDPE can achieve complete melting with relatively lower thermal input and shorter cycle times, making it suitable for small-scale applications. This comparison underscores the novelty and practicality of the flat-plate heating method as a low-cost and accessible alternative to more complex recycling technologies.

The novelty of this study lies in its experimental validation of a low-cost, direct thermal recycling technique using a custom-built flat-plate heating system to melt commonly used plastic waste types: PET/PETE, HDPE, and LDPE. Unlike existing methods that rely heavily on complex chemical processing or industrial-scale extrusion, this research introduces a simple, scalable, and energy-conscious approach suitable for small-scale or decentralised waste management operations. Through a series of structured experiments, the study successfully demonstrated that all three plastic types can be melted efficiently using a controlled heating mechanism, with PET/PETE identified as the most energy-efficient material (1.157 KW) and HDPE requiring the highest thermal input (1.369 KW). The melting behaviour and thermal retention of each plastic were carefully monitored and compared, providing a valuable reference for optimising energy use in future recycling applications.

Furthermore, this research presents a comprehensive comparative thermal profile for each plastic, which is rarely found in previous literature at this operational scale. The data-driven insights into melting duration, temperature stability, and cooling rates contribute to the body of knowledge on plastic recycling technologies, particularly those that prioritise affordability, simplicity, and applicability in low-resource settings. By offering a viable alternative to more capital-intensive recycling infrastructure, this work opens new pathways for community-level initiatives and educational institutions to engage in localised plastic waste treatment, thus advancing the practical implementation of circular economy principles in developing regions.

4 Conclusion

This study investigated the feasibility of using a flat-plate heating system to recycle PET/PETE, HDPE, and LDPE plastics in small-scale applications. PET exhibited the lowest energy requirement (1.157 kW) and shortest melting time (44 minutes), making it the most favourable candidate, while HDPE showed the highest energy demand (1.369 kW). These results confirm the potential of flat-plate heating to provide comparative thermal insights and a practical route for low-cost plastic recycling. Unlike conventional thermal recycling systems, this method offers simplicity, affordability, and the potential for scalability in community-based or small-enterprise contexts. Its straightforward design lowers technological barriers and emphasizes accessibility. Nonetheless, the small sample size (0.2 kg) and lack of durability testing under continuous operation highlight important limitations. Future work should focus on scaling up, optimizing heat transfer efficiency, and integrating renewable energy sources. Life cycle and environmental impact assessments are also necessary to evaluate its role within sustainable and decentralized recycling frameworks.

References

[1] I. Hasanuddin, F. Faurantia, and I. Mawardi, "Fabrication and mechanical characterization of binderless boards from sugarcane bagasse fibers," *J. Polimesin*, vol. 23, no. 2, pp. 147–151, 2025.

[2] C. Budiyantoro, H. Sosiati, and J. W. Joharwan, "The influence of the number of recycling cycles on the thermal and physical properties of polypropylene," *J. Polimesin*, vol. 21, no. 4, pp. 438–444, 2023.

[3] M. Iwan, G. Gunarto, L. Lani, A. Rahmadi, M. Mursalin, and E. Julianto, "Development of a small scale thermoelectric generator integrated with a waste oil stove," *J. Polimesin*, vol. 23, no. 3, pp. 327–331, 2025.

[4] S. Akhmad and P. Prasetiyo, "Mesin Hotpress Untuk Recycle Plastik HDPE Dan Karakterisasi Faktor Pencetakan Terhadap Cacat Dan Konsumsi Energi," in *Seminar Nasional Riset Inovatif*, 2017, pp. 912–919.

[5] W. W. A. de Andrade, M. A. de Oliveira, and R. K. Vieira, "Evaluation of maintenance management of a thermoplastic industry using maintenance maturity model," *Procedia Comput. Sci.*, vol. 204, pp. 635–642, 2022, doi: https://doi.org/10.1016/j.procs.2022.08.077.

[6] S. S. Borkar *et al.*, "Enabling resource circularity through thermo-catalytic and solvent-based conversion of waste plastics," *Chem Catal.*, vol. 2, no. 12, pp. 3320–3356, 2022.

[7] U. B. Surono, "Berbagai metode konversi sampah plastik menjadi bahan bakar minyak," *J. Tek.*, vol. 3, no. 1, 2013.

[8] K. Kusmiyati and A. Fudholi, "A Systematic Literature Review on The Pyrolysis of Plastic Waste and Waste Oil for Fuel Production: Targeted Waste Management Solution for Central Java, Indonesia," *Clean. Waste Syst.*, p. 100308, 2025, doi: https://doi.org/10.1016/j.clwas.2025.100308.

[9] S. Vellaiyan, D. Chandran, R. Venkatachalam, K. Ramalingam, R. Rao, and R. Raviadaran, "Maximizing waste plastic oil yield and enhancing energy and environmental metrics through pyrolysis process optimization and fuel modification," *Results Eng.*, vol. 22, p. 102066, 2024, doi: https://doi.org/10.1016/j.rineng.2024.102066.

[10] V. Tuli, C. Luo, B. Robinson, J. Hu, and Y. Wang, "Microwave-assisted catalytic technology for sustainable production of valuable chemicals from plastic waste with enhanced catalyst reusability," *Chem. Eng. J.*, vol. 489, p. 151551, 2024, doi: https://doi.org/10.1016/j.cej.2024.151551.

[11] Z. Jiang *et al.*, "Microwave-Assisted Pyrolysis-A New Way for the Sustainable Recycling and Upgrading of Plastic and Biomass: A Review," *ChemSusChem*, vol. 17, no. 21, p. e202400129, 2024.

[12] N. Zhou *et al.*, "Catalytic pyrolysis of plastic wastes in a continuous microwave assisted pyrolysis system for fuel production," *Chem. Eng. J.*, vol. 418, p. 129412, 2021, doi: https://doi.org/10.1016/j.cej.2021.129412.

[13] V. Tournier *et al.*, "An engineered PET depolymerase to break down and recycle plastic bottles," *Nature*, vol. 580, no. 7802, pp. 216–219, 2020.

[14] V. Soni *et al.*, "Upcycling of polyethylene terephthalate (PET) plastic wastes into carbon-based nanomaterials: Current status and future perspectives," *Eur. Polym. J.*, vol. 215, p. 113249, 2024, doi: https://doi.org/10.1016/j.eurpolymj.2024.113249.

[15] C. Charlier *et al.*, "An NMR look at an engineered PET depolymerase," *Biophys. J.*, vol. 121, no. 15, pp. 2882–2894, 2022, doi: https://doi.org/10.1016/j.bpj.2022.07.002.

[16] X. Liu *et al.*, "Exploring biotechnology for plastic recycling, degradation and upcycling for a sustainable future," *Biotechnol. Adv.*, vol. 81, p. 108544, 2025, doi: https://doi.org/10.1016/j.biotechadv.2025.108544.

[17] Y. Fang, Y. Wen, L. Dai, C.-H. Wang, S. You, and W. Li, "Artificial intelligence in plastic recycling and conversion: A review," *Resour. Conserv. Recycl.*, vol. 215, p. 108090, 2025, doi: https://doi.org/10.1016/j.resconrec.2024.108090.
[18] A. Chapman, K. K. Sen, T. Mochida, Y. Yoshimoto, and K. Kishimoto, "Overcoming barriers to proactive plastic recycling toward a sustainable future," *Environ. Challenges*, vol. 17, p. 101040, 2024, doi: https://doi.org/10.1016/j.envc.2024.101040.