

Inductively heated plastic pyrolysis over by H-ZSM5 zeolite and fluid catalytic cracking catalyst

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Highlights

- High carbon footprint of plastic pyrolysis hampers large-scale application.
- Plastic pyrolysis via induction heating reduces heating time and energy consumption.
- Plastic pyrolysis over HZSM-5 produced high gas yield, which is rich in C2 and C3 molecules.
- Induction heating of plastic pyrolysis will play a key role in net-zero circular economy of plastics.
- Availability of low-carbon electricity supply reduces the carbon emission of new plastic economy.

1. Introduction

Pyrolysis technology plays a critical role in circular carbon extraction from plastic waste, displacing fossil feedstock from the circular economy of plastics envisioned by Ellen MacArthur Foundation. Nevertheless, the high temperature required by pyrolysis translates to high carbon footprint for large scale application. The potential of induction heating in chemical process electrification has been demonstrated, for example in carbon capture (Gholami et al., 2022), steam reforming (Kim et al., 2023), ammonia production (Ponikvar et al., 2022). Such an enabling technology could also link plastic pyrolysis to renewable electricity, allowing acceleration towards a net-zero circular economy of plastics in 2050 proposed by SYSTEMIQ (2022). Nevertheless, several bottlenecks remains hindrances towards large-scale application of plastic pyrolysis technology. This work reports energy-efficient and fast conversion of plastics into light hydrocarbons via inductively heated plastic pyrolysis, which provides a potential strategy to reduce carbon footprint of plastic pyrolysis.

2. Methods

LDPE, HDPE, and PP pellets (particle size: 3–5 mm) were used as received. Catalysts used were ZSM-5 catalyst (CBV 2314) and spent fluid catalytic cracking (E-cat). A stainless steel fixed bed reactor system which could be inductively heated was used. Plastic pellets and the catalysts were placed in the middle section of the reactor between the layers of quartz wool. The reactor also acted as a susceptor in an alternating magnetic field produced by an induction heater. A stainless-steel cold trap connected to the bottom reactor outlet was maintained at 2 °C to collect the condensable reaction products. The non-condensable gases were collected in a water column placed after the cold trap. In plastic pyrolysis, 1.00 g of plastic pellets, together with 0.20 g of catalyst, were placed on 0.20 g of a quartz wool layer in the reactor. Before the pyrolysis process, the reactor system was purged with nitrogen gas (120 mL/min) for 10 min. The induction heater was turned on for 30 min to allow reactor heating. If the wax product was formed in the

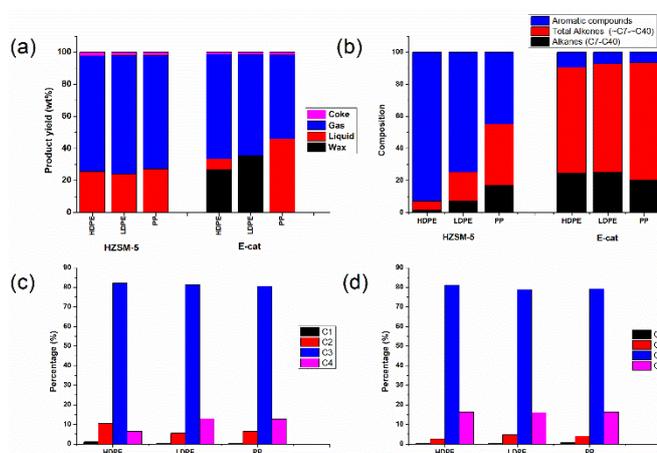


Figure 1. Product yield (a) and liquid product compositions for catalytic pyrolysis over HZSM-5 and E-cat, and compositions of gas products for pyrolysis over HZSM-5 (c) and E-cat (d).

cold trap, the wax was collected and weighed. If a liquid product was formed, it was extracted with 3 mL of dichloromethane before being weighed and analyzed. Induction heating successfully raised the reactor temperatures to 500–700 °C within 10 min.

3. Results and discussion

Temperature measurements indicated that induction heating successfully raised the reactor temperatures to 500–700 °C within 10 min. The heating rate of the system is estimated to be 50–85 °C/min depending on the induction heater power.

Thermal pyrolysis of plastics produced high wax yield (72.4–73.9 wt%). The presence of catalysts in plastic pyrolysis reduced the wax yield while increasing the gas and liquid yields significantly (Fig. 1a). When HZSM-5 zeolite was used, all the plastics were converted to liquid products (24.0–27.2 wt%) and gas products (345.0–448.0 cm³/g). Despite the inferior textural properties (compared to HZSM-5) and absence of strong Brønsted acidic sites, E-cat demonstrated catalytic activity in plastic pyrolysis within a short reaction time. A careful examination of the chromatograms of liquid products shows that catalytic pyrolysis of HDPE and LDPE possessed similar product distributions, while the liquid products from PP pyrolysis showed different product characteristics. This is clear evidence of the influence of plastic structures on the product formation route during pyrolysis. Liquid products from catalytic pyrolysis of HDPE and LDPE over HZSM-5 contained hydrocarbons with carbon numbers in C7-C15, while those from catalytic pyrolysis over E-cat C5-C35 hydrocarbons, represented by peaks with lower heights. Such observations indicate a wide product distribution (Fig. 1b).

In all experiments, rapid gas evolution was observed between 3 and 5 min (corresponding to the temperature of 450–550 °C). After 10 min, complete plastic conversion into volatile products occurred. The presence of catalysts significantly increased the product gas evolutions to different degrees. The microporous structure and high acidic properties of HZSM-5 promoted a high degree of plastic cracking, leading to the formation of liquid products and more C1-C4 products (Fig. 1c). In comparison, catalytic pyrolysis over E-cat produced a lower amount of gas products (Fig. 1d). This is attributed to the less severe plastic cracking due to the lower acidity of the catalyst (Section 3.2). To illustrate the advantage of induction heating in plastic pyrolysis, the electrical energy consumed by the induction heater during plastic pyrolysis was measured using a C.A 8436 Qualistar+ Power Quality analyser (Chauvin Arnoux). Measurements under different conditions show that the electrical energy consumption was independent of the masses of plastics and catalysts during pyrolysis (as heat energy was supplied in excess to the reaction system) and was only related to the induction heater power and reactor dimensions. The electrical energy consumed during 10 min of plastic pyrolysis was 228 kJ (\approx 63.4 Wh) (Fig. S9a, Supplementary materials). This value is significantly lower than those recorded by Wu et al. [64] for biomass pyrolysis, namely 665.2 kJ at 550 °C (with the presence of metal hollow balls) and 819.9 kJ (without the presence of metal hollow balls) at 600 °C.

4. Conclusions

This exploratory study demonstrates the feasibility of new pyrolysis powered by induction heating in the production of different value-added products from plastics. The adoption of induction heating could be an interesting strategy that reduces the time needed for plastic waste pyrolysis, especially at a larger scale. In addition, the prospects of applying induction heating on stainless-steel reactors also provide an interesting scaling-up strategy that allows possible pressure variation. As induction heating is also known to have higher energy conversion efficiency than resistive heating, future studies will be dedicated to the quantification of energy consumption in plastic pyrolysis assisted with induction heating.

References

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Keywords

Pyrolysis; plastics; electrification; catalyst.