Advancing Sustainable Waste Management: An Experimental Investigation of Two-Step Pyrolysis for Enhanced Plastic Solid Waste Valorization

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Highlights

- The cracking temperature has a significant effect on the yields of co-products.
- Not only the yields, but also the quality of the gas is influenced by the cracking temperature.
- The process includes mechanisms that are established under certain operating conditions.

1. Introduction

The escalating global issue of plastic solid waste (PSW) demands urgent and sustainable solutions. In light of environmental concerns and resource conservation, recycling plays a pivotal role in mitigating the impact of PSW. Among various recycling approaches, pyrolysis has emerged as a promising technology for transforming plastic waste into added-value products that can act as chemicals or fuels [1]. This process involves the thermal breakdown of plastics in the absence of oxygen [2]. The use of a two-step pyrolysis allows working with two separate reactors, whose operating variables can be independently adjusted. This aspect can be beneficial for a future project on larger scales. We aim to contribute to the development of sustainable waste management, making an experimental study on the two-step pyrolysis which allows to determine the effects of temperature on quantity of co-products and quality of gas one.

2. Methods

This study investigates the pyrolysis treatment of industrial and urban treated plastic solid waste (PSW). Once characterized, the PSW, featuring an apparent density of 60 kg/m^3, 3 wt% moisture content, and 10 wt% inert fraction, undergoes batch testing simulating a two-step pyrolysis process on a laboratory scale. The experimental design consists of three main sections: a reaction section with two reactors (pyrolysis and cracking) transforming plastic waste into four phases (two solid ones, one vapor, and one gas); a separation section employing condensation for heavy and light component separation; and an analysis section where the gaseous phase, collected in bags, undergoes microGC analysis for volumetric composition determination. Co-products masses are obtained from the experimental setup, facilitating the calculation of percentage yield. The two tubular reactors are inertized with nitrogen, and heated using two electric furnaces. The first reactor is maintained at 600°C, while the second have a temperature varying between 600, 650, 700, and 800 °C. Each test at these temperatures is repeated twice, providing a comprehensive method that encompasses waste treatment, experimental design, and analytical processes for evaluating the pyrolysis of PSW.

3. Results and discussion

The main results obtained from this study are presented below.

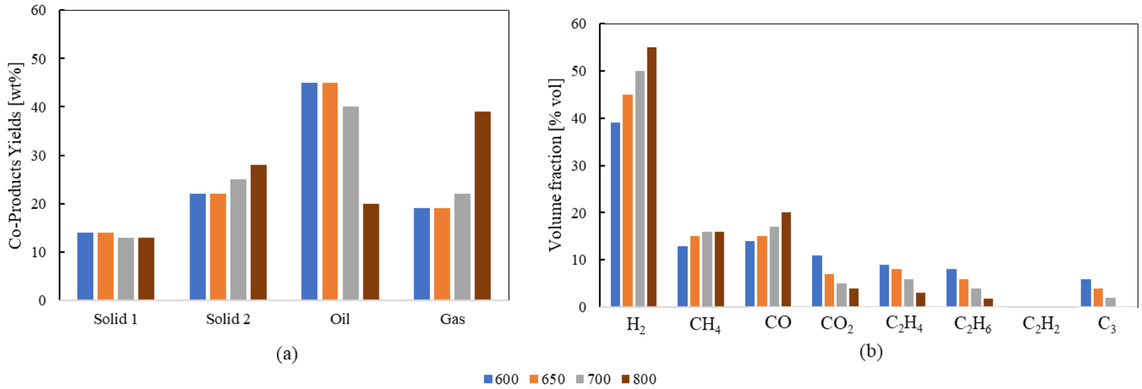

Figure 1. Co-products yields (a) and Pyrolysis gas composition (b) obtained with experimental tests.

In Figure 1(a), the effect of the cracking reactor temperature on the yields of co-products is depicted. It is observed that the gas yield increases slightly from 600°C to 700°C, while a sudden increase is evident when transitioning from 700°C to 800°C. This outcome can be explained by considering an increase in homolytic dissociation and beta-scission of bonds, leading to an increase in the production of solid 2 and a reduction in oil production, as confirmed by the obtained results. In Figure 1(b), the effect of the same parameter on the composition of the pyrolysis gas is studied. As expected, following the same mechanisms, an increase in cracking temperature leads to an increase in the more volatile components and a reduction in the heavier ones. Equally interesting is observing the behavior of CO and CO2; as the temperature increases, the percentage of CO increases at the expense of CO2. This phenomenon can be explained by the Boudouard equilibrium. The other calculated parameter of fundamental importance is the lower heating value (LHV) of the gas, which increases from 31 MJ/kg at 600°C to 33 MJ/kg at 800°C.

4. Conclusions

This study presents a comprehensive investigation into the thermochemical conversion of real plastic solid waste. The detailed characterization of the waste served as a crucial starting point, followed by experimentation using an experimental setup featuring two distinct reactors. Through systematic temperature variations in the second reactor, we demonstrated the ability to induce significant changes in yields beyond a critical temperature threshold. Importantly, this study highlights the potential for triggering these mechanisms without relying on catalysts, which, while advantageous, pose challenges at the industrial level in terms of cost and production difficulties. The findings contribute valuable insights to the field of plastic waste conversion and provide a basis for further exploration of efficient and economically viable thermochemical processes.

References

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Keywords
Experimental investigation, two-step pyrolysis, plastic solid waste.