Influencing the product quality in chemical recycling of mixed thermoplastics by temperature-staged pyrolysis

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Abstract

The transformation from fossil to sustainable input materials is one of the current challenges facing the chemical industry. Due to its heterogeneous composition, numerous plastic waste fractions are not mechanically recycled but can be further used by applying thermochemical conversion processes, e.g. gasification or pyrolysis. In pyrolysis, the carbon- and hydrogen-rich plastic waste is converted into gaseous, condensable, and solid products. In particular, condensable pyrolysis products are considered as alternative feedstock for (petro-)chemical processes such as steam cracking and fluid catalytic cracking. However, these products often fail to fulfill the common specifications of existing petrochemical feedstocks [1]. This is caused by its contents of nitrogen- and halogen-containing molecules and by the presence of unsaturated hydrocarbons. Emerging aromatics impair the efficiency by reducing the target product yields in these processes. The use of pyrolysis condensates is therefore associated with additional costs as a result of the required separation processes or additional upgrading. Temperature-staged pyrolysis has the potential to overcome these issues by impacting both product yields and product composition when adapting process parameters to the mixed thermoplastics waste composition.

A temperature-staged pyrolysis process has shown that the selective separation of chlorine is feasible (e.g. [2]). In this case, the chlorine content in the condensable pyrolysis product is reduced significantly by implementing a primary low-temperature pyrolysis stage to convert chlorine selectively to HCl ahead of secondary hydrocarbon pyrolysis. Furthermore, nitrogenous substances and aromatics are generated separately from hydrocarbons in an elevated pyrolysis temperature range.

In this work, the feasibility of temperature-staged pyrolysis is investigated for mixed thermoplastic feedstocks. An experimental study of the most commonly used thermoplastics (LDPE, HDPE, PP, PS, ABS, PET, PA6, PVC) is performed in laboratory scale to examine their decomposition behavior in co-pyrolysis. Interactions occur between specific plastic types, which can influence the pyrolysis behavior of the mixture in comparison to the pure polymer. As a result, the staged temperature concept can be extended to cover oxygen-containing pyrolysis products from PET, for example. Accordingly, it enables the generation of liquid products with adaptable composition due to the enrichment of molecule groups in dedicated fractions. Chlorine is removed and short-chain length pyrolysis condensate with increased heteroatom and aromatic content is separated from aliphatic-rich pyrolysis oil. The enrichment of various product groups facilitates the targeted use of the condensate fractions by fraction-specific product upgrading and composition-adapted processing in subsequent petrochemical processes. Staged pyrolysis can thus contribute to achieving specification-compliant alternative feedstocks as part of a circular plastics economy.

[1] Kusenberg M., Eschenbacher, A., Djokic, M. R., Zayoud A., Ragaert, K., De Meester, S., Van Geem, M. (2022). Opportunities and challenges for the application of post-consumer plastic waste pyrolysis oils as steam cracker feedstocks: To decontaminate or not to decontaminate?. Waste Manage. DOI: 10.1016/j.wasman.2021.11.009
[2] Bockhorn H., Hornung A., Hornung U. (1999). Stepwise pyrolysis for raw material recovery. J. Anal. Appl. Pyrolysis. DOI: 10.1016/S0165-2370(98)00066-7