**Decentralized plastic waste recycling through pyrolysis – a feasibility study**

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**Highlights**

* Decentralized recycling of plastic waste.
* Process modeling and techno-economic assessment
* Pyrolysis of pure and mixed plastic fractions

**1. Introduction**

Plastic materials play a major role in society but pose certain challenges. Accumulation in nature has adverse effects on wildlife, and most plastics are currently produced from fossil resources which contradicts the demands on climate change mitigation stated by the UN. Today, a large part of plastic waste is incinerated or landfilled [1]. Legislators are raising the bar for recycling rates, with the EU setting a target of 50 % recycling of plastic packages by 2025 [2]. While mechanical recycling of plastics is efficient, it requires high feed purity and cannot be repeated indefinitely as the material degrades slightly over each cycle.

Meanwhile, thermo-chemical processes like pyrolysis and gasification can decompose plastics into their basic monomers, with lower requirements on feed purity. Pyrolysis of mixed plastics to obtain pyrolysis oil is well researched and companies are presently trying to commercialize the process [3, 4]. However, the potential for pyrolysis of pure plastic streams requires further research. Through pyrolysis, polymers like polystyrene (PS) and poly methyl methacrylate (PMMA) can be cracked into their monomers and repolymerized, allowing a less complex process design [5, 6]. The profitability of such a process will depend on how it is designed, as well as the scale of the plant.

The purpose of this study is to investigate the economic incentives for decentralized recycling of plastic waste, both in pure and mixed plastic fractions. There is a contradiction between achieving the economic benefits of a large process and transport associated costs relating to the corresponding geographical area from where the plastic feedstock is gathered. It is therefore of interest to investigate how a pyrolysis process can be designed to handle different types of plastic waste efficiently, and how large the plant would have to be to achieve economic feasibility. This study uses the Gothenburg region as a reference regarding waste flows, to assess the economic feasibility of implementing different pyrolysis-based processes.

**2. Methodology**

A literature study is conducted to estimate the quantity of plastics available in the region, and its composition with respect to different polymers. The mass and energy balance of the potential pyrolysis processes are attained through process modeling using process flow sheeting software Aspen Plus. Knowledge of the product stream composition from different polymers are attained through published literature on experimental studies on pyrolysis of polymers. The most promising polymer feeds are chosen based on the availability of polymer and the benefit of pyrolyzing it separately, i.e. polymers that generate a product with a high share of valuable chemicals. The pyrolysis reactor mass and energy balance are calculated explicitly to mimic published results. Downstream process equipment required to separate and/or refine the products into saleable fractions are rigorously modelled.

The concept of constructing a flexible process which can use different pure plastic streams as well as mixed plastic streams is compared to processes handling a single type of plastic. Capital investment cost is estimated applying the Taylor method [7] as well as using the cost estimation tool in Aspen plus to get a larger span of the capital investment cost. Along with the feedstock and operational costs, the product revenue and economic performance is estimated for each process.

The economic performance depends on the recycling efficiency of the process. There is a tradeoff between product purity and capital costs; recovering more of the products and increasing purity generates more revenue but also requires more process steps and/or larger separation equipment. At a certain point, raising the recycling efficiency starts to have a negative impact on the overall economic performance. After optimizing the plant design, the size of the plant is varied to find the smallest size that is economically feasible, compared to the current waste handling system. The minimum size of the process is then compared to the size of available waste flows in the Gothenburg region, to assess the feasibility of implementation.

**3. Results**

Based on issues related to current waste treatment and potential value of the pyrolysis products, two types of pure plastic fractions have been identified as particularly interesting, Polystyrene for production of styrene and Polyvinylchloride (PVC) for production of HCl and alkanes or propene, depending on reactor temperature. These are compared to a mixed plastic fraction for production of ethylene.

**References**

1. Plastics-the facts 2018: An analysis of European plastics production, demand and waste data. Available at <https://www.plasticseurope.org/en/resources/publications/619-plastics-facts-2018>.
2. Council Directive (EU) 2018/852 of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste, art. 5.
3. Lopez G, Artetxe M, Amutio M, Alvarez J, Bilbao J, Olazar M. Recent advances in the gasification of waste plastics. A critical overview. Renewable and Sustainable Energy Reviews, 82(September 2017):576–596, 2018.
4. The RT7000 [Internet]. Swindon: Recycling Technologies; 2018 [Retrieved: 2019-02-13]. Available at: <https://recyclingtechnologies.co.uk/technology/the-rt7000/>.
5. Achilias DS, Kanellopoulou I, Megalokonomos P, Antonakou E, Lappas AA. Chemical recycling of polystyrene by pyrolysis: Potential use of the liquid product for the reproduction of polymer. Macromolecular Materials and Engineering, 292(8):923–934, 2007.
6. Kikuchi Y, Hirao M, Ookubo T, Sasaki A. Design of recycling system for poly(methyl methacrylate) (PMMA). Part 1: Recycling scenario analysis. International Journal of Life Cycle Assessment, 19(1):120–129, 2014.
7. TAYLOR, J. H. The ‘process step scoring’method for making quick capital estimates. Engineering and Process Economics, 1977, 2.4: 259-267.