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Opinion

# Transforming Naphtha Steam Crackers for Plastic Waste and Biogenic Feedstocks

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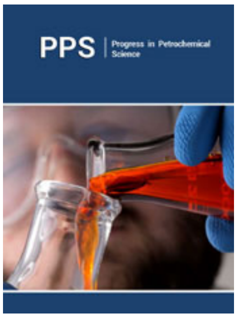


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## Opinion

In an era where sustainability and profitability are crucial, conventional naphtha steam crackers are increasingly challenged by competing processes and stringent environmental regulations. A pioneering approach from Chalmers University of Technology in Sweden presents a promising solution. This innovative method also addresses the inefficiencies of current plastic recycling methods and paves the way for the transition toward a circular economy. The rise of low-cost alternative feedstocks like ethane and LPG, combined with advanced processes like CATOFIN® PDH that offer high selectivity for olefins directly from alkanes, has led to an oversupply of olefins in the petrochemical market. Additionally, the increasing costs associated with fossil $CO_2$ emissions make naphtha steam crackers less competitive than alternative olefin production methods, which have lower carbon emissions. As a result, operators of naphtha steam crackers in the European Union and Japan are shutting down their systems and seeking new market opportunities.

One such opportunity is repurposing naphtha steam crackers for the chemical recycling of plastics. This approach involves converting plastic waste into pyrolysis oil (PyOil) at distributed pyrolysis plants. The PyOil is then transported to centralized naphtha crackers, where it is processed into light olefins and monoaromatics. However, crude PyOil contains unsaturated hydrocarbons and contaminants such as oxygen, nitrogen, and chlorine, which make it unsuitable for direct use in naphtha steam crackers. Crude PyOil must undergo extensive upgrading through distillation and hydrotreatment to serve as a drop-in feedstock for naphtha steam crackers.

The level of unsaturation and contaminants in PyOil can be reduced if the feedstocks for the pyrolysis unit meet strict quality specifications. However, the composition of waste feedstock varies by season and region over time, making it difficult to maintain consistent quality. Additionally, in the European Union, pyrolysis units processing waste fall under stringent environmental regulations, making it economical challenging to operate units having a feedstock capacity of less than 100,000 tons per year. While this capacity may be small for a naphtha cracker, it poses a significant challenge in securing a waste stream with a specific composition. Although operators of pyrolysis units often receive guarantees on the composition of delivered waste feedstock, maintaining compliance is difficult. Given these challenges, many researchers and companies have concluded that producing drop-in naphtha from plastic waste in significant quantities to replace naphtha in conventional steam crackers is not a viable solution.

An innovative solution developed at Chalmers University of Technology offers a way forward by revamping conventional steam crackers to handle complex feedstocks. This innovative approach uses fluidized bed technology, enabling the direct processing of plastic waste and biogenic materials. The new configuration not only enhances feedstock flexibility but also addresses the limitations in current plastic recycling methods, bridging plastic waste management with the fossil-free production of new plastics. At Chalmers University of Technology, the fluidized bed steam cracking approach has been explored for nearly a decade. While this method is similar to Fluid Catalytic Cracking (FCC), natural ores, such as silica sand, are used instead of a catalyst. That makes the Chalmers process a pure thermal cracking method similar to a conventional steam cracker. The basic principle involves introducing the feedstock to the surface of a hot, bubbling fluidized bed, which transfers heat to the feedstock. Inert or unconverted fractions are retained in the bed or captured by downstream filters. The unconverted fraction is oxidized in the combustion section of the process to generate heat. The inert fractions are removed from the bed as fly ash or bottom ash. Thus, this setup enables a steam cracker to process feedstocks with high ash content and a tendency to form coke.

Although FCC-like systems have been proposed for converting naphtha into light olefins, they have not reached commercial viability, likely due to increased CO and $CO_2$ production from the enhanced water-gas shift reaction in fluidized bed systems, necessitating additional downstream gas treatment. Regardless of the water-gas shift reaction, processes for removing CO and $CO_2$ from the product gas remain essential when using mixed plastic wastes which unavoidably come with oxygen. Additionally, undesirable byproducts such as HCl, $NH_3$ and $H_2S$ originate from plastic waste in steam crackers, for which established removal methods are available; for example, limestone effectively removes HCl in fluidized bed processes. Thus, undesirable products can either be managed within the fluidized bed steam cracker or through downstream treatment.

A few research groups around the world are working to advance this process. Notable examples include Chalmers in Sweden, VTT in Finland, TNO in the Netherlands and BEST-Bioenergy and Sustainable Technologies GmbH in Austria. At Chalmers, a semi-industrial unit has been operating since 2016, capable of processing up to 10 tons of mixed plastic waste per day. This unit has conducted weekly experimental campaigns with various plastic mixtures and other feedstocks, yielding valuable insights into the technological potential. The feedstock flexibility of the process has been well-validated. It performs as efficiently as a conventional naphtha cracker when processing pure naphtha into olefins and monoaromatics. Similarly, it can process polyolefin-derived crude PyOil, obtaining similar olefin yields. These consistent results extend to different feedstocks, including mixed plastic wastes, raw animal fats and vegetable oils. Moreover, the process can also produce valuable gas mixtures from highly heterogeneous waste streams, such as automotive shredder residues and lignocellulosic biomasses.

At this stage, it can be concluded that a fluidized bed steam cracker, capable of handling coke-forming and ash-containing feedstocks, could be a viable alternative to conventional naphtha crackers. This approach would facilitate a transition to renewable and recycled feedstocks by replacing the cracker furnaces while retaining the existing downstream gas separation equipment. If adopted, this technology could also create a market for unsaturated and contaminated PyOils produced in distributed units, overcoming the limitations imposed by conventional steam crackers.

This text is based on the published article "Circular Use of Plastics: Transformation of Existing Petrochemical Clusters into Thermochemical Recycling Plants with 100% Plastics Recovery," in Sustainable Materials and Technologies, Volume 22, December 2019, e00124. An extensive summary of the experimental results from semi-industrial operations is provided in the recent doctoral thesis titled "Steam Cracking in Dual Fluidized Beds: One Step Towards Complete Recyclability of Plastic Waste Using Thermochemical Conversion," from Chalmers University of Technology, 2024, ISBN 978-91-8103-0088. A popular science presentation of the concept is available on YouTube under the title "Waste-From a Problem to a Valuable Feedstock."