Electrothermal Reactor Design and Circular Feedstock for Low-Carbon Olefin Production

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CLB 366 | Zoom: https://udel.zoom.us/j/95385313777| (Password: Olefins)

The chemical industry is a major consumer of fossil energy and a significant source of greenhouse-gas emissions, with olefin manufacturing among its most energy- and carbon-intensive sectors. Decarbonizing olefin production requires addressing both process heat and carbon feedstocks. This thesis develops a multiscale chemical reaction engineering framework for decarbonized olefin manufacturing by integrating electrothermal reactor design with circular feedstock utilization.

First, direct electrification through Joule-heated reactors is investigated. Computational modeling is used to quantify the coupled effects of electrical conduction, heat transfer, and fluid flow in steady-state and dynamic operation, establishing how reactor design and operating conditions govern temperature control, transient behavior, and process intensification. A complementary framework for Joule-heating material and element selection is then developed to identify how material properties and structural features determine heating rate, temperature uniformity, startup efficiency, and operational stability.

These electrothermal principles are applied to short-contact-time ethane cracking for ethylene production. This work shows that internal Joule heating enables high-temperature, short-residence-time operation that increases ethylene yield while suppressing methane and aromatic byproducts relative to conventional practice. The results also indicate the potential for reduced capital costs and lower emissions when coupled with low-carbon electricity.

The thesis then addresses circular carbon integration through plastic waste valorization. Because mixed polymer melts are highly viscous, non-Newtonian, and strongly temperature dependent, transport limitations can dominate reactor performance. To overcome this challenge, a reactor-scale framework for non-isothermal multi-polymer melt processing is developed. The results demonstrate that close-clearance anchor-based configurations provide markedly better mixing, thermal uniformity, and active circulation than conventional magnetic stirring, thereby establishing practical design principles for scalable polymer processing.

Finally, we develop an integrated framework to identify plastic-derived naphtha compositions that maximize the economic benefit. The results show that its economic viability depends strongly on feed composition, sourcing cost, and retrofit strategy, and that favorable integration is possible within realistic industrial constraints.

Overall, this thesis shows that decarbonized olefin manufacturing can be achieved through the coordinated design of electrothermal reactors, polymer-specific operating units, and circular feedstock integration. By linking reactor-scale transport, material selection, process intensification, and industrial deployment within a unified framework, this work provides new design principles for lower-emission and economically viable olefin production.