Advances in Process Intensification through Multifunctional Reactor Engineering

Novel Reactor Concept Promises Increased Efficiency

Process intensification is a key strategy that the chemical industry is adopting to increase energy efficiency and profitability. Multifunctional reactors (i.e., chemical reactors that integrate other functions such as separations) form the cornerstone of process intensification. Catalytic distillation is the classic example of multifunctional reaction engineering. Multiphase catalytic reactors, operating in the pulse flow regime, offer significant improvements in energy efficiency and process performance from enhanced mass and heat transfer. However, multiphase catalytic reactors currently do not operate in pulse-flow mode and existing pulse-flow reactors are over designed and operate at less than optimal efficiency.

Chemical Research and Licensing Company (CR&L), ABB Lummus, and Sandia National Laboratories seek to develop a multiphase, pulse-flow catalytic reactor for acid catalyzed C4 paraffin/olefin alkylation. The technology will allow to optimize existing trickle-bed reactors, such as refinery hydrotreaters. Other processes that could benefit include those that utilize liquid catalysts, such as phosphoric acid, nitric acid, or ionic liquids. Applications that could benefit include 1) higher capacity vapor/liquid catalytic downflow reactors with fixed-bed catalyst systems, 2) vapor/liquid/liquid reactors in which the catalyst is one of the liquid phases or is contained in one of the liquid phases, and 3) vapor/liquid upflow reactors utilizing a homogeneous catalyst slurry.

Sandia's Slurry Bubble-Column Reactor (SBCR) testbed. Over the last decade, Sandia's Slurry Bubble-Column Reactor (SBCR) testbed has been successfully used to support indirect liquefaction studies.

Benefits for Our Industry and Our Nation

A multiphase catalytic reactor operating in the pulse flow regime could result in energy savings of up to 83 trillion Btu per year through improved mass and heat transfer. The technology also promises to reduce solid waste though the reduction in acid use for alkylation.

Applications in Our Nation's Industry

The process is being developed specifically for acid catalyzed C4 paraffin/olefin alkylation. However, these novel multiphase catalytic reactors could benefit other processes across the chemical industry. In particular, processes that use liquid catalysts, such as phosphoric acid, nitric acid, or ionic liquids, will enjoy significant improvements in performance and efficiency.

Project Description

The overall objective of the project is to develop the knowledge and tools required to develop and scale a novel multiphase pulse-flow, catalytic reactor for acid catalyzed C4 paraffin/olefin alkylation, to industrial dimensions.

Barriers

Major barriers to be overcome include the following:

- No three-phase (vapor/liquid/liquid) commercial pulse-flow reactors currently exist
- Commercial reactors that operate in pulse-flow were originally designed to operate under trickle-flow conditions resulting in significant over design and operation at less than optimal efficiencies
- Mechanism that initiates pulse-flow is not well understood and associated time-dependence of pulse-flow requires a scale-up criterion that is beyond current engineering practice
- Lack of fundamental understanding required for scaling up pulse-flow catalytic reactors to industrial-scale operations

Pathways

This project will consist of interrelated experimentation (bench-scale and pilot-scale) and modeling tasks. The bench-scale experiments will focus on materials characterization, process chemistry, and structure-scale hydrodynamics. The pilot-scale experiments will focus on vessel-scale hydrodynamics. Project partners will also investigate the transition between trickle-flow and other modes and the characteristics of the changes. The team will develop detailed models of structure-scale processes, which will be incorporated into a vessel-scale hydrodynamics model.

Progress and Milestones

- Fabricate bench-scale multifunctional reactor (completed)
- Fabricate pilot-scale multifunctional reactor and packing (completed)
- Conduct two- and three-phase bench-scale testing
- Conduct three-phase pilot-scale testing and evaluate packing
- Optimize alkylation process

Commercialization

CR&L and ABB Lummus have formed the joint venture Catalytic Distillation Technologies (CDTECH) to develop and market new technologies for the refining, chemical, and petrochemical industries. CR&L focuses on developing the technologies for the CDTECH portfolio and Lummus focuses on marketing these technologies. In this project, CR&L and Sandia will collaborate in the research and development of the pulse-flow catalytic reactor. Once the technology is demonstrated, the CDTECH will use its marketing team to bring the pulse-flow reactor technology to the marketplace.

Project Partners

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