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Systematic process design of a styrene production plant using a hierarchical 12 task procedure: Waste stream utilization for improved sustainability.

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Monomeric styrene is consumed in large quantities for the production of polystyrene polymers. Improvements of the traditional process have been developed continually in order to improve product yield and reduce utility costs[1]. However, the process is still highly energy consuming due to the high temperatures and pressures required for the reactions, as well as the necessary purification of the crude styrene that is produced. As such, development of a more efficient and sustainable process is highly desirable in terms of economic savings and reduced environmental impact.

In this study, a process design for a styrene production plant is developed based on ethylene alkylation of benzene to ethylbenzene and a subsequent isothermal dehydrogenation of ethylbenzene to styrene. The developed process design has a capacity of approximately 150,000 tons of 99.92 wt% styrene per year, along with a recovery of approximately 4000 and 2500 tons per year of industrial grade toluene and hydrogen byproducts, respectively. Various options for utilizing the recovered hydrogen gas are considered. In order to reduce raw material consumption, polyethylbenzenes are recovered and reacted with benzene to form ethylbenzene in a transalkylation reaction. The recovery of ethylbenzene, polyethylbenzene, styrene, and benzene for recirculation, is performed using distillation columns.

The process design is developed according to a systematic 12 task procedure for process design[2 3]. The 12 tasks are solved hierarchically, and can be summarized as follows. Tasks 1-2: Investigation of the product(s), chemical process(es), and economic potential. Task 3: Process synthesis in order to obtain a process flowsheet. Task 4: Solution of the mass balance of the process flow sheet using simple models. Task 5: Specification of operating conditions. Task 6: Solution of the energy balance of the process flowsheet. Task 7: Simulation of the process using rigorous models for the various unit operations. Task 8-9: Equipment sizing and costing calculations along with an economic evaluation. Task 10-12: Heat and mass integration, environmental impact considerations, and process optimization. To facilitate the solution of the tasks, the commercial software PRO/II is used to simulate the process. Sustainable design alternatives for the process are evaluated using SustainPro, while a life cycle assessment is carried out using LCSoft.

By solving the 12 tasks, an efficient process design is obtained. This includes an investigation of more sustainable alternatives to the traditional styrene synthesis; the focus of this investigation being efficient recovery and utilization of the hydrogen produced by the dehydrogenation of ethylbenzene as well as optimized heat integration between unit operations. For the utilization of the hydrogen, two design cases are investigated: (i) Utilizing the hydrogen as fuel for plant burners, and (ii) recovery of the hydrogen to be sold on the global market.

Keywords: Process Design & Development, Sustainable Engineering

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