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Snapshots of

FROM SMALL BATCH TO LARGE-SCALE CONTINUOUS PROCESSES

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The chemical process industries are probably the least understood of all manufacturing sectors, largely because few final products are sold directly to consumers. The chemical process industries are perhaps best summarized by the BASF ad: "We don't make the products you buy, we make the products you buy, better." A consumer who purchases an automobile generally has some appreciation for the sequence of steps involved in an assembly line to produce the vehicle. Most consumers, however, have a lesser understanding of the chemical processes involved in producing plastics for the dashboard, fabrics for the seats, glass for the windshield, and polymers for the tires. One goal of this special section, part II of the August 2006 special section, is to provide control engineers with a better understanding of various chemical processes and their control challenges.

The August 2006 issue focused on biological-based chemical processes, with topics ranging from large-scale pulp and paper processes to crystallization operations with tight control over crystal size, shape, and structure. The topics covered in this issue range from small batch processes for specialty chemicals and pharmaceutical production to large-scale petroleum refineries with continuous processes.

The first article by Bonvin, Srinivasan, and Hunkeler covers batch processes, which are

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often used in the specialty chemicals and pharmaceuticals industries. Scaleup is extremely important, since much of the fundamental chemistry research is performed in one-liter and smaller vessels, with further studies in pilot plant vessels with 100–1,000-l volumes, and, finally, manufacturing-scale vessels larger than 50,000 l. The decrease in surface-area-to-volume ratio can make it difficult to remove the heat from large-scale reactors. Batch-to-batch control techniques are often used to improve the operating profiles as information is collected from previous batch runs. An example chemical reaction, with one desired reaction and three reactions that produce unwanted species, illustrates common challenges involved in producing an intermediate compound in a batch reactor.

The second article by Martinez and Edgar is on photolithography processes in semiconductor device manufacturing. Semiconductor processes are also largely batch in nature, and run-to-run control is the dominant strategy since quality and performance measurements are often available only at the end of each batch operation. In a lithography overlay process example, run-to-run control is implemented in a model predictive control framework, yielding improved overlay error and increased production capacity.

Cement manufacturing is the topic of the article by Sahasrabudhe, Sistu, Sardar, and Gopinath, who note that China produces 45% of the world's cement. Cement manufacturing is extremely energy intensive, and particular challenges include raw material variability; an example is an increase in limestone feedstock moisture content due to monsoons. While manual control is used in many existing plants, the authors describe the use of model predictive control for handling multivariable interactions and reducing energy consumption in the grinding process.

The article by Ydstie and Jiao is on float glass processing. The melter part of a glass furnace, which is 60-m long and 10-m wide, operates at around 2,200 °F and produces up to 700 tons of molten glass each day. A major challenge of the overall process is that from three to five days are needed to change over from green glass to clear glass, resulting in reworked product (off-spec product that is melted and reprocessed) and wasted energy, thus motivating the need for advanced strategies that can speed up the change over. Temperature constraints are also important and have a major impact on furnace lifetime. The authors show how a passivity-based inventory control system results in a substantial decrease in product defects while increasing production rate and decreasing energy consumption.

Petroleum refineries are probably the most identifiable chemical processes since many of the final products are used by consumers. Crude oil is a mixture of an extremely large number of organic molecules, with a low fraction that can be used directly in gasoline. About half of every barrel of crude oil is converted to gasoline, and numerous reaction and separations processes are involved in gasoline production. As noted in the article by Young, real-time optimization forces these complex, integrated systems to operate near constraints, which is one reason for the evolution and success of model predictive control in the petroleum refining industry.

The final article by Bequette provides an overview of U.S. fuel energy uses and then discusses the current technologies used to reform natural gas into hydrogen. A major challenge in the operation of steam reforming furnaces is that higher conversions and rates of reaction require high temperatures that reduce furnace tube lifetime; model predictive control is the best technique for satisfying temperature constraints. In the long term, hydrogen production for use in fuel cells must come from sustainable sources, such as water (using thermochemical cycles or wind and solar energy) or biomass. The article also discusses ethanol and biodiesel production processes.

The two special sections contain articles that focus on challenges in particular industries, such as pulp and paper, as well as specific unit operations, such as biochemical reactors. I encourage authors to submit articles on other chemical process industries and unit operations to future issues of *IEEE Control Systems Magazine*.

Editing these two special issues has been a rewarding experience, giving me the opportunity to better understand chemical process control challenges in a range of industries. I would like to thank the authors for their efforts in writing articles for readers without a process control background.