B. WAYNE BEQUETTE

A FOCUS ON BIOLOGICAL SYSTEMS

Snapshots of Process Control

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Process control, to a large extent, implies chemical process control, which has traditionally been the domain of chemical engineers. An aerospace engineer entering a process control session at an American Control Conference may feel that a different language is being spoken: with notions of exothermic reactions, recycle streams, cascade and ratio control as well as a plethora of acronyms, such as RGA, MPC, and PID. For example, while proportional-integral-derivative (PID) control is commonly used in many disciplines, the notion of a process and instrumentation diagram is specific to the chemical process industries. A goal of this special issue is to provide an overview of the economic importance of chemical processes and their challenging control problems to control systems engineers working in other disciplines. A secondary audience is chemical engineering students looking for motivating process examples for their chemical process control courses.

The articles in this special section, and a future companion section, are illustrative of the broad range processes that are modeled, designed, and operated by chemical process engineers. Bulk petrochemicals, pulp and paper, and cement are typically produced using large scale processes. On the other hand, chemical processes in the semiconductor, specialty chemicals, and pharmaceutical industries are substantially smaller in scale. These articles include *unit operations*, which produce an intermediate product, and *processes*, which contain an integrated set of unit operations and often produce one or more final product streams.

Broadly speaking, a chemical process is a process in which a molecular transformation occurs. One or more feed streams typically undergo a sequence of pumping/compression, heating/cooling, reaction and separation operations before yielding several product streams. Since these product streams rarely result directly in a consumer product, most people have a limited understanding of the important role of chemical processes in the numerous products that they use during their daily lives.

The authors of these articles were asked to discuss the economic importance of a unit operation or process; provide a sense of scale (size of equipment and annual production rate); discuss measurements, manipulated (control) and disturbance inputs, the importance of nonlinearities and constraints, and representative control techniques; discuss process development, including bench scale and pilot plant studies, simulations, and the retrofit of existing processes; and finally, provide a prospective view of the future of the process or technology. Our goal is to provide control engineers without a process control background with a better understanding of chemical processes.

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CHARACTERISTICS

Chemical reaction rates are a strong, nonlinear function of temperature. Chemical streams must often be heated to a high enough temperature for a reasonable rate of reaction, and then the products must be cooled for further processing or storage. Equilibrium thermodynamics often dictates the final conversion, and one reactant is usually supplied in significant excess of the amount required by the reaction stoichiometry. The excess reactant and unconverted limiting reactant are usually separated from the product mixture and recycled to the reactor. Recycle streams serve as a positive feedback to the process, often substantially increasing the dynamic time scale and rendering the process sensitive to disturbances.

Chemical processes have unique control challenges compared to device (component) or discrete manufacturing processes. A disk drive manufacturer can justify the resources to develop an advanced control algorithm to be used in millions of disk drives. Chemical process plants that produce a specific product are often few in number, however, and each plant may have a different design, feedstock, or final product slate. In addition, each plant has a different management culture, operating philosophy, and distributed control system software and hardware. Thus, each chemical process plant requires a distinctly different control design from similar plants.

SPECIAL ISSUE ARTICLES

Various acronyms are used in these "Snapshots of Process Control" articles. The PID controller is the workhorse of the process industries, used in virtually every control loop. Decentralized control is frequently used, with the relative gain array (RGA), as the analytical tool to suggest the best pairings of measured outputs and manipulated inputs to form independent single-input, single-output (SISO) controllers. Model predictive control (MPC) is the primary advanced control strategy, with MPC outputs as setpoints to lower level PID control loops.

The articles in this special issue have biological systems as a common theme. Wood, a renewable resource, is the feedstock for pulp and paper processes. A paper machine has a production rate of 300,000 tons per year and consumes 100,000 kg/h of steam and 10 MW of electricity, as noted in the article by Mercandoz and Doyle. MPC is often used for the cross-direction machine control problem, where 20–300 actuators control paper thickness on sheets that are 10 m wide and moving at 30 m/s.

The next article by Nikoloau presents numerous chemical and biological processes that are involved in snack food manufacturing. It is interesting that complex behavior, such as multiple steady states, known to occur in exothermic chemical reactors, can also be observed in extrusion cookers. Like many chemical processes, a difficulty in food process manufacturing is that a direct measure of product quality is rarely available in real time for feedback control.

The article by Henson notes that basic chemical process principles have been applied in the pharmaceutical, food, and biotechnology industries for over 50 years. The production of penicillin in the 1940s involved 25,000-gal fermentation vessels and downstream separations processes to purify the dilute penicillin product stream from the fermentors. Large-scale fermentation processes are also used to produce fuel ethanol from corn.

The fourth article, by Hamilton, Braun, Dare, Koopman, and Svoronos, reviews waste treatment plants, which process millions of gallons of wastewater each day with roughly a 4:1 diurnal variation in flow. These plants consist of aeration basins, which are large (millions of gallons) biological reactors, along with settling tanks and filtration equipment. While simple PID and related control algorithms predominate, the authors find that automatic control of dissolved oxygen yields an annual savings of US$60,000–180,000 over manual control.

Crystallization is a unit operation used to produce a wide range of products, from ice cream to semiconductors, as discussed in the article by Larsen, Patience, and Rawlings. While limited measurements make robust process design important in many industries, advanced measurement and imaging techniques are increasingly used to more precisely control crystal structure in pharmaceutical products.

CONCLUSIONS

I would like to thank the authors for their substantial effort in writing articles for those without expertise in the processes covered. I hope that these chemical process control snapshots spark interest in process control and encourage discussions between chemical process engineers and the control community at large.