AUTOMATION AND CONTROL OF CHEMICAL AND PETROCHEMICAL PLANTS

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Summary

The operation of modern chemical and petrochemical plants would be very difficult, if not impossible, without automation and computer control. Safe efficient plant operation requires that thousands of process variables be controlled within specified limits. Today the typical process control system in a large continuous plant is an integrated network of computers, operator workstations, instrumentation, and other control hardware. Although the traditional PI and PID control algorithms are the most widely used control techniques, advanced control methods such as model predictive control can provide significant improvements for difficult multivariable control problems.

Since the 1980s, the chemical and petrochemical industries have faced major challenges due to global competition and rapid changes in economic conditions. Consequently, there has been increased emphasis on operating plants more efficiently and economically. Since the 1980s, advanced automation, process control, and on-line optimization have played key roles in improving plant performance. Today there is increased emphasis on using computer networks to integrate process control activities with other plant and business activities, in order facilitate the effective coordination of manufacturing activities at the enterprise level.

1. Introduction

The chemical and petrochemical industries produce a wide variety of products that are essential for modern industrialized societies. Chemicals are the building blocks for products that meet fundamental needs for food, health, and consumer products. Chemicals are also essential to wide range of industries such as pharmaceuticals, automobiles, textiles, furniture, paint, paper, electronics, agriculture, construction, and appliances. The fuels produced by petrochemical plants play a vital role in meeting our and energy and transportation requirements. Although there are legitimate concerns about the environmental and safety issues associated with these industries, it is very difficult to imagine how industrialized societies could sustain a high standard of living without these products. The operation of modern industrial plants would not be feasible without automation and process control. This paper provides an overview of process control objectives and methodology in the chemical and petrochemical industries. But at first, the basic background material for these industries will be presented.

2. The Chemical and Petrochemical Industries

The chemical and petrochemical industries are a key component of the world economy, as will be illustrated by a few statistics. The world production of chemicals for 1999 has been estimated at €1370 billion (or $1592 billion U.S. dollars.). Table 1 indicates that about 85% of this world chemical production is divided equally among three regions: Western Europe, the United States, and Japan.

Asia/Pacific	$466
Western Europe	458
United States	435
South & Central America	88
Central/Eastern Europe	50
Africa	31
Mideast	28
Canada	21
Mexico	15
Total:	**$1,592**

Table 1. World Output of Chemicals for 1999 (in 10^9 U.S. dollars)

Rank	Chemical	Amount	Rank	Chemical	Amount
1	Sulfuric acid	45.1	6	Propylene	14.6
2	Nitrogen	33.8	7	Phosphoric acid	13.8
3	Oxygen	30.8	8	Chlorine	13.3
4	Ethylene	28.4	9	Ethylene dichloride	11.4
5	Ammonia	19.0	10	Sodium hydroxide	11.4

Table 2. Chemicals with The Largest U.S. Production Rates for 1999
(10^6 tons per year).

(Reference: *Chemical & Engineering News*, June, 26, 2000)

In the United States, the chemical industry is the third largest manufacturing sector, representing approximately 10% of all manufacturing. More than 70,000 different products are registered in the United States. Table 2 lists the 10 chemicals that were produced in the largest quantities in 1999.

Petroleum products have been the world's major energy sources for decades. The projections in Table 3 indicate that this trend is expected to continue.

Oil	40%
Natural gas	26%
Coal	24%
Nuclear	5%
Renewables	3%

Table 3. World Energy Demand Projections for the Year, 2020.
(Reference: International Energy Agency)

The refining of crude oil produces a wide range of products that are used for energy and chemical feed stocks, as shown in Table 4.

Product	Quantity*
gasoline	19.5
distillate fuel oil (includes heating oil & diesel fuel)	9.2
kerosene-type jet fuel	4.1
residual fuel oil (heavy oils used as fuels)	2.3
liquefied refinery gasses	1.9
still gas	1.9
coke	1.8
asphalt and road oil	1.3
petrochemical feedstocks	1.2
lubricant	0.5
kerosene	0.2
other	0.3

* The total number of gallons is larger than 42 U.S. gallons because the liquid volumes are not conserved.

Table 4. Products from a barrel of crude oil (in U.S. gallons per barrel)
(Reference: American Petroleum Institute)

Chemical and petrochemical plants vary from small facilities that produce single products to complex manufacturing facilities that produce a wide range of products and occupy several square miles. Large manufacturing plants are located worldwide and require huge capital resources to build. Historically, plant sites have been situated close to raw materials and/or product distribution centers.

Chemicals produced in small quantities (e.g., less that 1000 tons per year) are typically manufactured in *batch processes*. A batch process consists of a series of separate activities that are performed in a sequential manner. In a typical batch process, the raw materials and additives such as catalysts are initially placed in a closed container (i.e., a process *vessel*). Then the process is initiated (e.g., by heating the vessel or turning on a stirring device) and a series of steps (a *recipe*) are followed. Finally, the product is removed from the vessel and transferred to another vessel for further processing or storage. Batch processes are also used when a high degree of flexibility is required to accommodate frequent changes in product grades and marketplace demands. Many pharmaceuticals, polymers, paints, and specialty chemicals are produced in batch processes. Cooking food on a stove or in an oven is a familiar example of a batch process. Chemical and petrochemicals that are manufactured in large quantities are produced in *continuous processes*. In a continuous process, a *feed stream* of raw materials is continuously added to the process unit and a product stream is continuously withdrawn. Large continuous processes tend to be operated "around the clock", i.e., 24 hours per day, 7 days a week, with shutdowns for planned maintenance occurring once or twice each year. Continuous processes are attractive candidates for the application of advanced process control and optimization techniques because a small reduction in the unit cost of product results in huge annual savings due to the large production rate. This paper will emphasize control of continuous processes due to their economic importance and their heavy reliance on control and automation.

Since the 1980s, the chemical and petrochemical industries have faced a number of critical business and technical challenges:

1. Increased global competition;
2. Enormous fluctuations in raw material, energy, and chemical product prices;
3. Increased customer demand for high quality products;
4. More stringent environmental and safety regulations.

Due to uncertain economic conditions and the large capital costs associated with the manufacturing plants, it is not feasible to redesign the plant to meet each new challenge. Consequently, there has been increased emphasis on operating plants more efficiently and economically. Since the 1980s, advanced automation, process control, and on-line optimization have played key roles in improving plant performance.

3. Historical Perspective

Early industrial plants were controlled manually using only a few measurements. The modern era began in the 1920s and 1930s when automatic feedback control was used to control individual process variables such as liquid levels, pressures, flow rates, and temperatures. The introduction of automation was particularly beneficial when the control actions were tedious and repetitious. The first generation of instrumentation and controllers consisted of pneumatic (i.e., air powered) devices. At first only proportional feedback control was used; later, integral and derivative control modes were added. In these early applications, the controllers and recorders were mounted locally, close to the equipment being controlled. But in the 1930's, it became possible to transmit pneumatic signals, such as measurements and controller outputs, over long distances. This breakthrough allowed control equipment to be consolidated in central control rooms with subsequent reductions in manpower. Electronic instruments and controllers entered the marketplace during the 1950s. They were analog devices that had continuous input and output signals. The first digital computer control applications were reported in the late 1950s and early 1960s. A typical first generation computer control system had 32KB of memory, one MB of disk storage, and required one second to retrieve stored information from the disk. These early computers were mainly used for data acquisition and as information systems. Automatic chemical composition analyzers that could be used "on line" as part of a feedback control system, were introduced during the 1960s. Simple digital devices, called *programmable logic controllers (PLCs*), became available in the 1970s. They are still widely used for relatively simple control applications that involve programmable logic and sequencing operations.

A major breakthrough occurred in 1975 when the first generation of *distributed control systems (DCS*) was introduced. The DCS systems consisted of networks of microprocessors and small computers that were connected to each other and to instruments by redundant "data highways". The control functions were distributed among the computers so that each computer would control a small number of process variables (e.g., 8-16 variables) but coordination among computers could still be achieved. The man-machine interface was greatly enhanced by using modern computer monitors. In the late 1970s, the first industrial applications of modern model-based control techniques were reported in France and the United States. In the mid-1980s, personal computers were introduced into the DCS systems, further enhancing the flexibility, computing power, and man-machine interfaces. Today, the process control systems in large continuous plants typically consist of integrated networks of computers, operator workstations, instrumentation, and other control hardware. The current revolution in information technology is having a major effect on a variety of process control activities. *Smart instruments* have embedded microprocessors that perform routine signal processing activities and provide improved diagnostics. Digital communication networks such as *Fieldbus* and *Profibus* rely on open architecture and published international standards. There is increased emphasis on using computer networks to integrate process control activities with other plant and business activities, in order facilitate the effective coordination of manufacturing activities at the enterprise level.

It is somewhat surprising and ironic that despite the dramatic improvements in automation and information technology, the vast majority (85-95%) of the feedback control loops in the process industries are based on the proportional-integral (PI) and proportional-integral-derivative (PID) control techniques that originated in the 1930s. But although *advanced control techniques* are only used in a small percentage of the total control loops, the economic impact of these critical control loops is significant and justifies the additional effort. Another anomaly is that pneumatic control valves are still widely used to regulate the flow rates of liquids and gases. Thus, current process control strategies provide an effective blend of the old and the new.

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Biographical Sketch

Dale E. Seborg is a Professor of Chemical Engineering at the University of California, Santa Barbara. He received his B.S. degree from the University of Wisconsin and his Ph.D. degree from Princeton University. Before joining UCSB in 1977, he taught at the University of Alberta for nine years. He also served as the department chair at UCSB for a three year period.

Dr. Seborg has published over 150 articles on process control & related topics, and is the co-author of a widely used textbook, *Process Dynamics and Control* (1989), with Professors Duncan Mellichamp (UCSB) and Tom Edgar (UT-Austin). Their textbook has been translated into Korean (1995) and Japanese (1996). Dr. Seborg is also co-editor of three books including a 1996 book, *Nonlinear Process Control*, with Professor Michael Henson (LSU). Dr. Seborg has taught a variety of industrial short courses around the world, including courses in Japan, China, Germany, Kuwait and Australia. He is also an active industrial consultant.

Dr. Seborg is the recipient, or co-recipient, of several national awards that include the American Statistical Association's *Statistics in Chemistry Award* (1994), the American Automatic Control Council's *Education Award* (1993), the American Society of Engineering Education's *Meriam-Wiley Distinguished Author Award* (1990), and the Joint Automatic Control Conference Best Paper Award (1973). He also received the *Technical Achievement Award* from the AIChE Southern California Section in 1980.

Among his numerous professional activities, Dr. Seborg was a co-organizer of the 2000 IFAC Symposium on System Identification and the General Chair for the 1992 American Control Conference. He also co-organized the Chemical Process Control (CPC-2) Conference and served as a director of the American Automatic Control Council and the AIChE CAST Division. Dr. Seborg currently serves on the editorial board of the *IEE Proc. on Control Theory and Applications.* Previously, he was an Associate Editor at Large for the *IEEE Trans. on Automatic Control*, and a member of the editorial boards for the *Int. J. HVAC & R Research* and the *Int. J. of Adaptive Control & Signal Processing*.