Introduction to Process Control

CHAPTER 1

1.1 INTRODUCTION

When observing a chemical process in a plant or laboratory, one sees flows surging from vessel to vessel, liquids bubbling and boiling, viscous material being extruded, and all key measurements changing continuously, sometimes with small fluctuations and other times in response to major changes. The conclusion immediately drawn is that the world is dynamic! This simple and obvious statement provides the key reason for process control. Only with an understanding of transient behavior of physical systems can engineers design processes that perform well in the dynamic world. In their early training, engineering students learn a great deal about steady-state physical systems, which is natural, because steady-state systems are somewhat easier to understand and provide appropriate learning examples. However, the practicing engineer should have a mastery of dynamic physical systems as well. This book provides the basic information and engineering methods needed to analyze and design plants that function well in a dynamic world.

Control engineering is an engineering science that is used in many engineering disciplines—for example, chemical, electrical, and mechanical engineering—and it is applied to a wide range of physical systems from electrical circuits to guided missiles to robots. The field of *process control* encompasses the basic principles most useful when applied to the physicochemical systems often encountered by chemical engineers, such as chemical reactors, heat exchangers, and mass transfer equipment.

Since the principles covered in this book are basic to most tasks performed by chemical engineers, control engineering is not a narrow specialty but an essential topic for all chemical engineers. For example, plant designers must consider the dynamic operation of all equipment, because the plant will never operate at steady state (with time derivatives exactly equal to zero). Engineers charged with operating plants must ensure that the proper response is made to the ever-occurring disturbances so that operation is safe and profitable. Finally, engineers performing experiments must control their equipment to obtain the conditions prescribed by their experimental designs. In summary, the task of engineers is to design, construct, and operate a physical system to behave in a desired manner, and an essential element of this activity is sustained maintenance of the system at the desired conditions—which is process control engineering.

As you might expect, process control engineering involves a vast body of material, including mathematical analysis and engineering practice. However, before we can begin learning the specific principles and calculations, we must understand the goals of process control and how it complements other aspects of chemical engineering. This chapter introduces these issues by addressing the following questions:

- What does a control system do?
- Why is control necessary?
- Why is control possible?
- How is control done?
- Where is control implemented?
- What does control engineering "engineer"?
- How is process control documented?
- What are some sample control strategies?

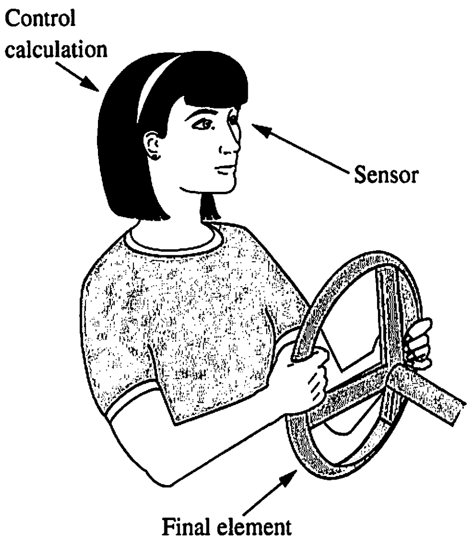


FIGURE 1.1

Example of feedback control for steering an automobile.

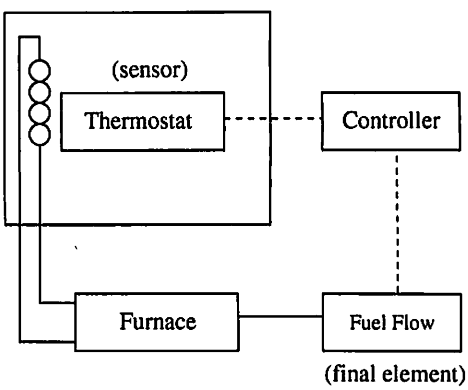


FIGURE 1.2

Example of feedback control for controlling room temperature.

1.2 ▪ WHAT DOES A CONTROL SYSTEM DO?

First, we will discuss two examples of control systems encountered in everyday life. Then, we will discuss the features of these systems that are common to most control systems and are generalized in definitions of the terms *control* and *feedback control.*

The first example of a control system is a person driving an automobile, as shown in Figure 1.1. The driver must have a goal or objective; normally, this would be to stay in a specific lane. First, the driver must determine the location of the automobile, which she does by using her eyes to see the position of the automobile on the road. Then, the driver must determine or calculate the change required to maintain the automobile at its desired position on the road. Finally, the driver must change the position of the steering wheel by the amount calculated to bring about the necessary correction. By continuously performing these three functions, the driver can maintain the automobile very close to its desired position as disturbances like bumps and curves in the road are encountered.

The second example is the simple heating system shown in Figure 1.2. The house, in a cold climate, can be maintained near a desired temperature by circulating hot water through a heat exchanger. The temperature in the room is determined by a thermostat, which compares the measured value of the room temperature to a desired range, say 18 to 22°C. If the temperature is below 18°C, the furnace and pump are turned on, and if the temperature is above 22°C, the furnace and pump are turned off. If the temperature is between 18 and 22°C, the furnace and pump statuses remain unchanged. A typical temperature history in a house in given in Figure 1.3, which shows how the temperature slowly drifts between the upper and lower limits. It also exceeds the limits, because the furnace and heat exchanger cannot respond immediately. This approach is termed "on/off" control and can be used when precise control at the desired value is not required. We will cover better control methods, which can maintain important variables much closer to their desired values, later in this book.

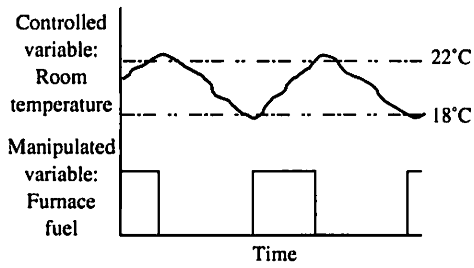


FIGURE 1.3

Typical dynamic response of the room temperature when controlled by on/off feedback control.

Now that we have briefly analyzed two control systems, we shall identify some common features. The first is that each uses a specific value (or range) as a desired value for the controlled variable. When we cover control calculations in Part III, we will use the term *set point* for the desired value. Second, the conditions of the system are measured; that is, all control systems use sensors to measure the physical variables that are to be maintained near their desired values. Third, each system has a control calculation, or *algorithm,* which uses the measured and the desired values to determine a correction to the process operation. The control calculation for the room heater is very simple (on/off), whereas the calculation used by the driver may be very complex. Finally, the results of the calculation are implemented by adjusting some item of equipment in the system, which is termed the *final control element,* such as the steering wheel or the furnace and pump switches. These key features are shown schematically in Figure 1.4, which can be used to represent many control systems.

Now that we have discussed some common control systems and identified key features, we shall define the term *control.* The dictionary provides the definition for the verb *control* as "to exercise directing influence." We will use a similar

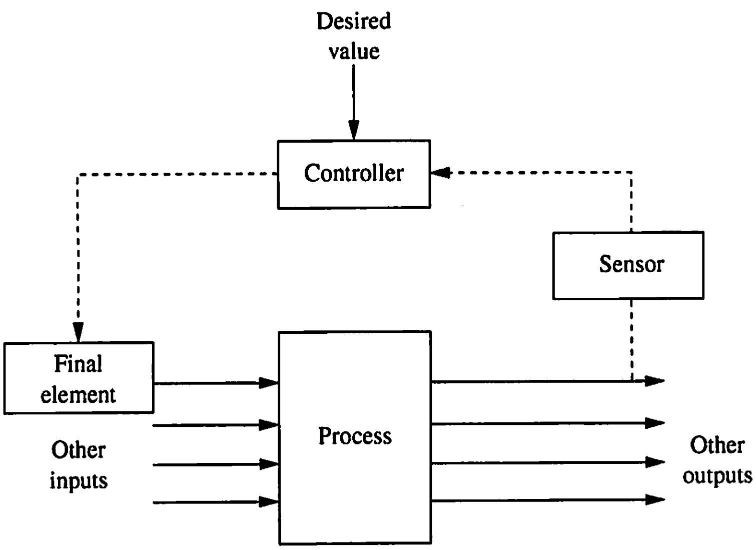


FIGURE 1.4

Schematic diagram of a general feedback control system showing the sensor, control calculation based on a desired value, and final element.

definition that is adapted to our purposes. The following definition suits the two physical examples and the schematic representation in Figure 1.4.

> **Control** (verb): To maintain desired conditions in a physical system by adjusting selected variables in the system.

The control examples have an additional feature that is extremely important. This is *feedback,* which is defined as follows:

> **Feedback control** makes use of an output of a system to influence an input to the same system.

For example, the temperature of the room is used, through the thermostat on/off decision, to influence the hot water flow to the exchanger. When feedback is employed to *reduce* the magnitude of the difference between the actual and desired values, it is termed "negative feedback." Unless stated otherwise, we will always be discussing negative feedback and will not use the modifier *negative.* In the social sciences and general vernacular, the phrase "negative feedback" indicates an undesirable change, because most people do not enjoy receiving a signal that tells them to correct an error. Most people would rather receive "positive feedback," a signal telling them to continue a tendency to approach the desired condition. This difference in terminology is unfortunate; we will use the terminology for automatic control, with "negative" indicating a change that tends to approach the desired value, throughout this book without exception.

The importance of feedback in control systems can be seen by considering the alternative without feedback. For example, an alternative approach for achieving the desired room temperature would set the hot water flow based on the measured outside temperature and a model of the heat loss of the house. (This type of predictive approach, termed *feedforward,* will be encountered later in the book, where its use in combination with feedback will be explained.) The strategy without feedback would not maintain the room near the desired value if the model had errors—as it always would. Some causes of model error might be changes in external wind velocity and direction or inflows of air through open windows. On the other hand, feedback control can continually manipulate the final element to achieve the desired value. Thus, feedback provides the powerful feature of enabling a control system to maintain the measured value near its desired value *without requiring an exact plant model.*

Before we complete this section, the terms *input* and *output* are clarified. When used in discussing control systems, they do not necessarily refer to material moving into and out of the system. Here, the term *input* refers to a variable that *causes* an output. In the steering example, the input is the steering wheel position, and the output is the position of the automobile. In the room heating example, the input is the fuel to the furnace, and the output is the room temperature. It is essential to recognize that the input causes the output and that this relationship cannot be inverted. The causal relationship inherent in the physical process forces us to select the input as the manipulated variable and the output as the measured variable. Numerous examples with selections of controlled and manipulated variables are presented in subsequent chapters.

Therefore, the answer to the first question about the function of control is, "A feedback control system maintains specific variables near their desired values by applying the four basic features shown in Figure 1.4." Understanding and designing feedback control systems is a major emphasis of this book.

1.3 ☐ WHY IS CONTROL NECESSARY?

A natural second question involves the need for control. There are two major reasons for control, which are discussed with respect to the simple stirred-tank heat exchanger shown in Figure 1.5. The process fluid flows into the tank from a pipe and flows out of the tank by overflow. Thus, the volume of the tank is constant. The heating fluid flow can be changed by adjusting the opening of the valve in the heating medium line. The temperature in the tank is to be controlled.

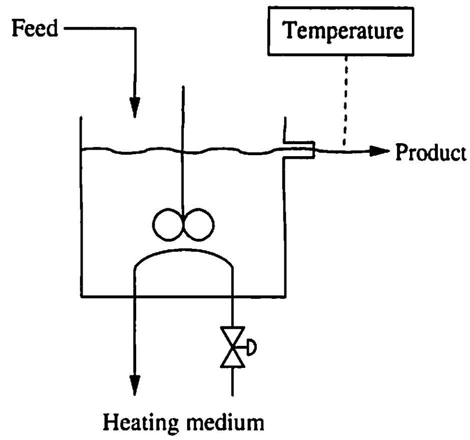


FIGURE 1.5

Schematic drawing of a stirred-tank heating process.

The first reason for control is to maintain the temperature at its desired value when *disturbances* occur. Some typical disturbances for this process occur in the following variables: inlet process fluid flow rate and temperature, heating fluid temperature, and pressure of the heating fluid upstream of the valve. As an exercise, you should determine how the valve should be adjusted (opened or closed) in response to an increase in each of these disturbance variables.

The second reason for control is to respond to changes in the *desired value.* For example, if the desired temperature in the stirred-tank heat exchanger is increased, the heating valve percent opening would be increased. The desired values are based on a thorough analysis of the plant operation and objectives. This analysis is discussed in Chapter 2, where the main issues are arranged in seven categories:

1. Safety
2. Environmental protection
3. Equipment protection
4. Smooth plant operation and production rate
5. Product quality
6. Profit optimization
7. Monitoring and diagnosis

These issues are translated to values of variables—temperatures, pressures, flows, and so forth—which are to be controlled.

1.4 ☐ WHY IS CONTROL POSSIBLE?

The proper design of plant equipment is essential for control to be possible and for control to provide good dynamic performance. Therefore, the control and dynamic operation is an important factor in plant design. Based on the key features of feedback control shown in Figure 1.4, the plant design must include adequate sensors of plant output variables and appropriate final control elements. The sensors must respond rapidly so that the control action can be taken in *real time.* Sensors using various physical principles are available for the basic process variables (flow, temperature, pressure, and level), compositions (e.g., mole fraction) and physical properties (e.g., density, viscosity, heat of combustion). Many of these sensors are inserted into the process equipment, with a shield protecting them from corrosive effects of the streams. Others require a sample to be taken periodically from the process; note that this sampling can be automated so that a new sensor result is available at frequent intervals. The final control elements in chemical processes are usually valves that affect fluid flows, but they could be other manipulated variables, such as power to an electric motor or speed of a conveyor belt.

Another important consideration is the capacity of the process equipment. The equipment must have a large enough maximum capacity to respond to all expected disturbances and changes in desired values. For the stirred-tank heat exchanger, the maximum duty, as influenced by temperature, area, and heating medium flow rate, must be large enough to maintain the tank temperature for all anticipated disturbances. This highest heat duty corresponds to the the highest outlet temperature, the highest process fluid flow, the lowest inlet fluid temperature, and the highest heat loss to the environment. Each process must be analyzed to ensure that adequate capacity exists. Further discussion of this topic appears in the next two chapters.

Therefore, the answer to why control is possible is that we anticipate the expected changes in plant variables and provide adequate equipment when the plant is designed. The adequate equipment design for control must be calculated based on *expected changes;* merely adding extra capacity, say 20 percent, to equipment sizing is not correct. In some cases, this would result in waste; in other cases, the equipment capacity would not be adequate. If this analysis is not done properly or changes outside the assumptions occur, achieving acceptable plant operation through manipulating final control elements may not be possible.

1.5 ▣ HOW IS CONTROL DONE?

As we have seen in the automobile driving example, feedback control by human actions is possible. In some cases, this approach is appropriate, but the continuous, repetitious actions are tedious for a person. In addition, some control calculations are too complex or must be implemented too rapidly to be performed by a person. Therefore, most feedback control is automated, which requires that the key functions of sensing, calculating, and manipulating be performed by equipment and that each element communicate with other elements in the control system. Currently, most automatic control is implemented using electronic equipment, which uses levels of current or voltage to represent values to be communicated. As would be expected, many of the computing and some of the communication functions are being performed increasingly often with digital technology. In some cases control systems use pneumatic, hydraulic, or mechanical mechanisms to calculate and communicate; in these systems, the signals are represented by pressure or physical position. A typical process plant will have examples of each type of instrumentation and communication.

Since an essential aspect of process control is instrumentation, this book introduces some common sensors and valves, but proper selection of this equipment for plant design requires reference to one of the handbooks in this area for additional details. Readers are encouraged to be aware of and use the general references listed at the end of this chapter.

Obviously, the other key element of process control is a device to perform the calculations. For much of the history of process plants (up to the 1960s), control calculations were performed by analog computation. Analog computing devices are implemented by building a physical system, such as an electrical circuit or mechanical system, that obeys the same equations as the desired control calculation. As you can imagine, this calculation approach was inflexible. In addition, complex calculations were not possible. However, some feedback control is still implemented in this manner, for reasons of cost and reliability in demanding plant conditions.

With the advent of low-cost digital computers, most of the control calculations and essentially all of the complex calculations are being performed by digital computers. Most of the principles presented in this book can be implemented in either analog or digital devices. When covering basic principles in this book, we will not distinguish between analog and digital computing unless necessary, because the distinction between analog and digital is not usually important as long as the digital computer can perform its discrete calculations quickly. Special aspects of digital control are introduced in Chapter 11. In all chapters after Chapter 11, the control principles are presented along with special aspects of either analog or digital implementation; thus, both modes of performing calculations are covered in an integrated manner.

For the purposes of this book, the answer to the question "How is control done?" is simply, "Automatically, using instrumentation and computation that perform all features of feedback control without requiring (but allowing) human intervention."

1.6 ▫ WHERE IS CONTROL IMPLEMENTED?

Chemical plants are physically large and complex. The people responsible for operating the plant on a minute-to-minute basis must have information from much of the plant available to them at a central location. The most common arrangement of control equipment to accommodate this need is shown in Figure 1.6. Naturally, the sensors and valves are located in the process. Signals, usually electronic, communicate with the control room, where all information is displayed to the operating personnel and where control calculations are performed. Distances between the process and central control room range from a few hundred feet to a mile or more. Some control is performed many miles from the process; for example, a remote oil well can have no human present and would rely on remote automation for proper operation.

In the control room, an individual is responsible for monitoring and operating a section of a large, complex plant, containing up to 100 controlled variables and 400 other measured variables. Generally, the plant never operates on "automatic pilot"; a person is always present to perform tasks not automated, to optimize operations, and to intervene in case an unusual or dangerous situation occurs, such as an equipment failure. Naturally, other people are present at the process equipment, usually referred to as "in the field," to monitor the equipment and to perform functions requiring manual intervention, such as backwashing filters. Thus, well-automated chemical plants involve considerable interaction between people and control calculations.

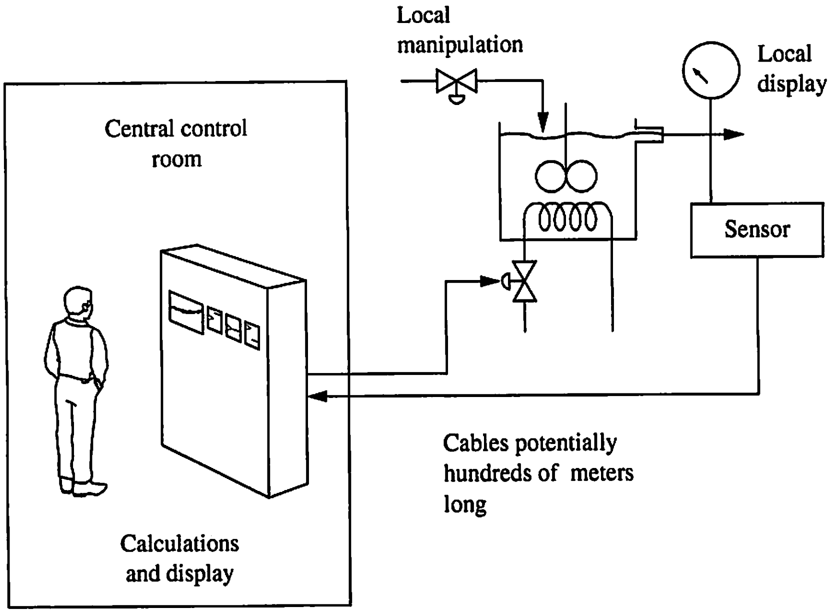


FIGURE 1.6

Schematic representation of a typical control system showing both local and centralized control equipment.

Other control configurations are possible and are used when appropriate. For example, small panels with instrumentation can be placed near a critical piece of process equipment when the operator needs to have access to the control system while introducing some process adjustments. This arrangement would not prevent the remainder of the plant from being controlled from a central facility. Also, many sensors provide a visual display of the measured value, which can be seen by the local operator, as well as a signal transmitted to the central control room. Thus, the local operator can determine the operating conditions of a unit, but the individual local displays are distributed about the plant, not collected in a single place for the local operator.

The short answer to the location question is

1. Sensors, local indicators, and valves are in the process.
2. Displays of all plant variables and control calculations are in a centralized facility.

It is worth noting that increased use of digital computing makes the distribution of the control calculation to the sensor locations practical; however, all controllers would be connected to a computing network that would function like a single computer for the purposes of the material in this book.

1.7 ▫ WHAT DOES CONTROL ENGINEERING "ENGINEER"?

What can engineers do so that plants can be maintained reliably and safely near desired values? Most of the engineering decisions are introduced in the following five topics.

Process Design

A key factor in engineering is the design of the process so that it can be controlled well. We noted in the room heating example that the temperature exceeded the maximum and minimum values because the furnace and heat exchanger were not able to respond rapidly enough. Thus, a more "responsive" plant would be easier to control. By *responsive* we mean that the controlled variable responds quickly to adjustments in the manipulated variable. Also, a plant that is susceptible to few disturbances would be easier to control. Reducing the frequency and magnitude of disturbances could be achieved by many means; a simple example is placing a large mixing tank before a unit so that feed composition upsets are attenuated by the averaging effects of the tank. Many more approaches to designing responsive processes with few disturbances are covered in the book.

Measurements

Naturally, a key decision is the selection and location of sensors, because one can control only what is measured! The engineer should select sensors that measure important variables rapidly and with sufficient accuracy. In this book, we will concentrate on the process analysis related to variable selection and to determining response time and accuracy needs. Details of a few common sensors are also presented as needed in exercises; a full review of sensor technology and commercial equipment is available in the references at the end of this chapter.

Final Elements

The engineer must provide *handles*—manipulated variables that can be adjusted by the control calculation. For example, if there were no valve on the heating fluid in Figure 1.5, it would not be possible to control the process fluid outlet temperature. This book concentrates on the process analysis related to final element location. We will typically be considering control valves as the final elements, with the percentage opening of these valves determined by a signal sent to the valve from a controller. Specific details about the best final element to regulate flow of various fluids—liquids, steam, slurries, and so forth—are provided by references noted at the end of this chapter. These references also present other final elements, such as motor speed, that are used in the process industries.

Control Structure

The engineer must decide some very basic issues in designing a control system. For example, which valve should be manipulated to control which measurement? As an everyday example, one could adjust either the hot or cold water valve opening to control the temperature of water in a shower. These topics are presented in later chapters, after a sound basis of understanding in dynamics and feedback control principles has been built.

Control Calculations

After the variables and control structure have been selected, equation(s) are chosen that use the measurement and desired values in calculating the manipulated variable. As we shall learn, only a few equations are sufficient to provide good control for many types of plants. After the control equations' structure is defined, parameters that appear in the equations are adjusted to achieve the desired control performance for the particular process.

1.8 ▫ HOW IS PROCESS CONTROL DOCUMENTED?

As with all activities in chemical engineering, the results are documented in many forms. The most common are equipment specifications and sizing, operating manuals, and technical documentation of plant experiments and control equations. In addition, control engineering makes extensive use of drawings that concisely and unequivocally represent many design decisions. These drawings are used for many purposes, including designing plants, purchasing equipment, and reviewing operations and safety procedures. Therefore, many people use them, and to avoid misunderstandings standard symbols have been developed by the Instrument Society of America for use throughout the world. We shall adhere to a reduced version of this excellent standard in this book because of its simplicity and wide application.

Sample drawings are shown in Figure 1.7. All process equipment—piping, vessels, valves, and so forth—is drawn in solid lines. The symbols for equipment items such as pumps, tanks, drums, and valves are simple and easily recognized. Sensors are designated by a circle or "bubble" connected to the point in the process where they are located. The first letter in the instrumentation symbol indicates the type of variable measured; for example, "T" corresponds to temperature. Some of the more common designations are the following:

- A Analyzer (specific analysis is often indicated next to the symbol, for example, ρ (for density) or pH)
- F Flow rate
- L Level of liquid or solids in a vessel
- P Pressure
- T Temperature

Note that the symbol does not indicate the physical principle used by the sensor. Backup tabular documentation is required to determine such details.

The communication to the sensor is shown as a solid line. If the signal is used only for display to the operator, the second letter in the symbol is "I" for indicator. Often, the "I" is not used, so that a single letter refers to a measurement used for monitoring only, not for control.

If the signal is used in a calculation, it is also shown in a circle. The second letter in the symbol indicates the type of calculation. We consider only two possibilities in this book: "C" for feedback control and "Y" for any other calculation, such as addition or square root. The types of control calculations are covered later in the book. A noncontrol calculation might use the measured flow and temperatures around a heat exchanger to calculate the duty; that is, $Q = \rho C_p F(T_{in} - T_{out})$. For controllers, the communication to the final element is shown as a dashed line when it is electrical, which is the mode communication considered in designs for most of this book.

The basic symbols with their meanings are documented in Appendix A. This simplified version of the Instrument Society of America standards is sufficient for

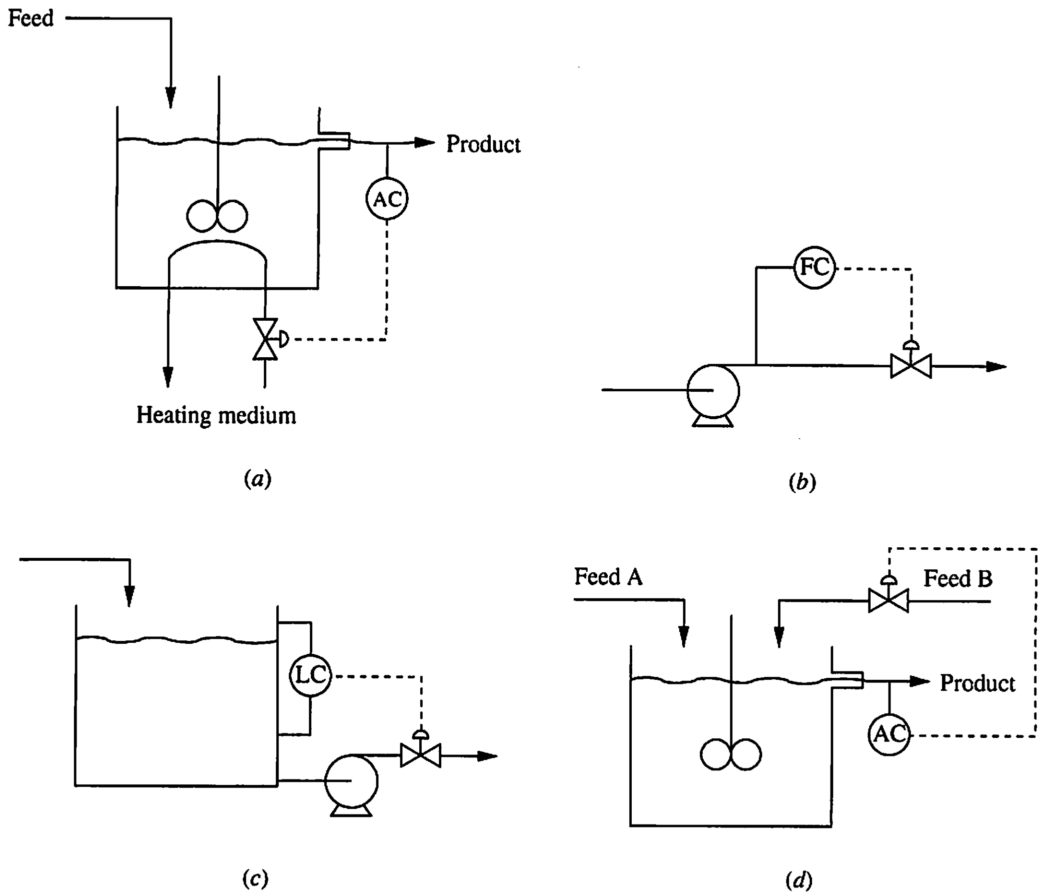


FIGURE 1.7

(*a*) Continuous stirred-tank reactor with composition control. (*b*) Flow controller. (*c*) Tank level with controller. (*d*) Mixing process with composition control.

this textbook and will provide an adequate background for more complex drawings. While using the standards may seem like additional work in the beginning, it should be considered a small investment leading to accurate communication, like learning grammar and vocabulary, used by all chemical engineers.

1.9 ▫ WHAT ARE SOME SAMPLE CONTROL STRATEGIES?

Some very simple example process control systems are given in Figure 1.7*a* through *d*. Each drawing contains a process schematic, a controller (in the instrumentation circle), and the connection between the measurement and the manipulated variable. As a thought exercise, you should analyze each process control system to verify the causal process relationship and to determine what action the controller would take in response to a disturbance or a change in desired value (set point). For example, in Figure 1.7*a*, with an increase in the inlet temperature, the control system would sense a decrease in the outlet composition of reactant. In response, the control system would adjust the heating coil valve, closing it slightly, until the outlet composition returned to its desired value.

A sample of a more complex process diagram, this one without the control design, is given in Figure 1.8. The process includes a chemical reactor, a flash

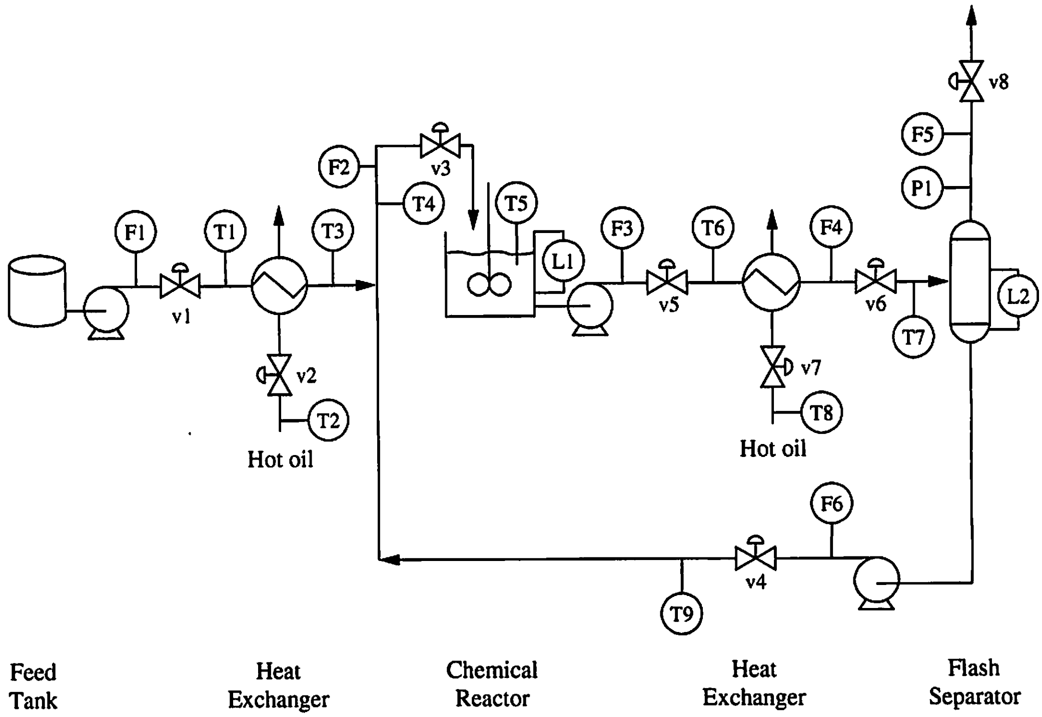


FIGURE 1.8

Integrated feed tank, reactor, and separator with recycle.

separator, heat exchangers, and associated piping. Note that a control design engineer must select from a large number of possible measurements and valves to determine controller connections from an enormous number of possibilities! In Chapter 25 *you* will design a control system for this process that controls the key variables, such as reactor level and separator temperature, based on specified control objectives.

1.10 ▫ CONCLUSIONS

The material in this chapter has presented a qualitative introduction to process control. You have learned the key features of feedback control along with the types of equipment (instruments and computers) required to apply process control. The importance of the process design on control was discussed several times in the chapter.

Based on this introduction, we are prepared to discuss more carefully the goals of process control in Chapter 2. Understanding the process control goals is essential to selecting the type of analysis used in control engineering.

REFERENCES

ISA, *ISA-S5.3, Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems,* Instrument Society of America, Research Triangle Park, NC, 1983.

ISA, *ISA-S5.1, Instrumentation Symbols and Identification,* Instrument Society of America, Research Triangle Park, NC, 1984.

ISA, *ISA-S5.5, Graphic Symbols for Process Displays,* Instrument Society of America, Research Triangle Park, NC, 1985.
ISA, *ISA-S5.4-1989, Instrument Loop Diagrams,* Instrument Society of America, Research Triangle Park, NC, July, 1989.
Mayer, Otto, *Origins of Feedback Control,* MIT Press, 1970.

ADDITIONAL RESOURCES

Process and control engineers need to refer to books for details on process control equipment. The following references provide an introduction to the resources on this specialized information.

Clevett, K., *Process Analyzer Technology,* Wiley-Interscience, New York, 1986.
Considine, R., and S. Ross, *Handbook of Applied Instrumentation,* McGraw-Hill, New York, 1964.
Liptak, B., *Instrument Engineers Handbook, Vol. 1: Process Measurements* and *Vol. 2: Process Control,* Chilton Book Company, Radnor, PA, 1985.
Driskell, L., *Control Valve Selection and Sizing,* ISA Publishing, Research Triangle Park, NC, 1983.
Hutchison, J. (ed.), *ISA Handbook of Control Valves* (2nd ed.), Instrument Society of America, Research Triangle Park, NC, 1976.
ISA, *Standards and Practices for Instrumentation and Control* (11th ed.), Instrument Society of America, Research Triangle Park, NC, 1992.

The following set of books gives a useful overview of process control, addressing both equipment and mathematical analysis.

Andrew, W., and H. Williams, *Applied Instrumentation in the Process Industries* (2nd ed.), *Volume I: A Survey,* Gulf Publishing, Houston, 1979.
Andrew, W., and H. Williams, *Applied Instrumentation in the Process Industries* (2nd ed.), *Volume II: Practical Guidelines,* Gulf Publishing, Houston, 1980.
Andrew, W., and H. Williams, *Applied Instrumentation in the Process Industries* (2nd ed.), *Volume III: Engineering Data and Resource Manual,* Gulf Publishing, Houston, 1982.
Zoss, L., *Applied Instrumentation in the Process Industries, Volume IV: Control Systems Theory, Troubleshooting, and Design,* Gulf Publishing, Houston, 1979.

The following references provide clear introductions to general control methods and specific control strategies in many process industries, such as petrochemical, food, steel, paper, and several others.

Kane, L. (Ed.), *Handbook of Advanced Process Control Systems and Instrumentation,* Gulf Publishing, Houston, 1987.
Matley, J. (Ed.), *Practical Instrumentation and Control II,* McGraw-Hill, New York, 1986.

The following are useful references on drawing symbols for process and control equipment.

Austin, D., *Chemical Engineering Drawing Symbols,* Halsted Press, London, 1979.

Weaver, R., *Process Piping Drafting* (3rd ed.), Gulf Publishing, Houston, 1986.

Finally, a good reference for terminology is

ISA, *Process Instrumentation Terminology,* ANSI/ISA S51.1-1979, Instrument Society of America, Research Triangle Park, NC, December 28, 1979.

QUESTIONS

1.1. Describe the four necessary components of a feedback control system.

1.2. Review the equipment sketches in Figure Q1.2*a* and *b* and explain whether each is or is not a level feedback control system. In particular, identify the four necessary components of feedback control, if they exist.

(*a*) The flow in is a function of the connecting rod position.

(*b*) The flow out is a function of the level (pressure at the bottom of the tank) and the resistance to flow.

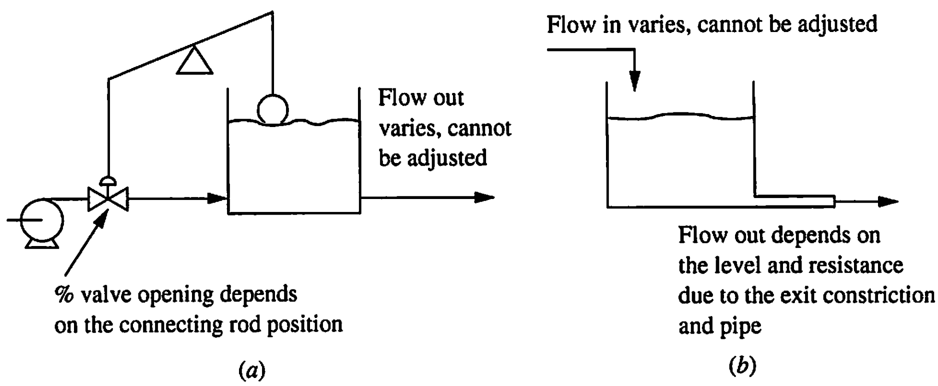


FIGURE Q1.2

1.3. Give some examples of feedback control systems in your everyday life, government, biology, and management. The control calculations may be automated or performed by people.

1.4. Discuss the advantages of having a centralized control facility. Can you think of any disadvantages?

1.5. Review the processes sketched in Figure 1.7*a* through *d* in which the controlled variable is to be maintained at its desired value.

(*a*) From your chemical engineering background, suggest the physical principle used by the sensor.

(*b*) Explain the causal relationship between the manipulated and controlled variables.
(*c*) Explain whether the control valve should be opened or closed to increase the value of the controlled variable.
(*d*) Identify possible disturbances that could influence the controlled variable. Also, describe how the process equipment would have to be sized to account for the disturbances.

1.6. The preliminary process designs have been prepared for the systems in Figure Q1.6. The key variables to be controlled for the systems are (*a*) flow rate, temperature, composition, and pressure for the flash system and (*b*) composition, temperature, and liquid level for the continuous-flow stirred-tank chemical reactor. For both processes, disturbances occur in the feed temperature and composition. Answer the following questions for both processes.
(*a*) Determine which sensors and final elements are required so that the important variables can be controlled. Sketch them on the figure where they should be located.
(*b*) Describe how the equipment capacities should be determined.
(*c*) Select controller pairings; that is, select which measured variable should be controlled by adjusting which manipulated variable.

(These examples will be reconsidered after quantitative methods have been introduced.)

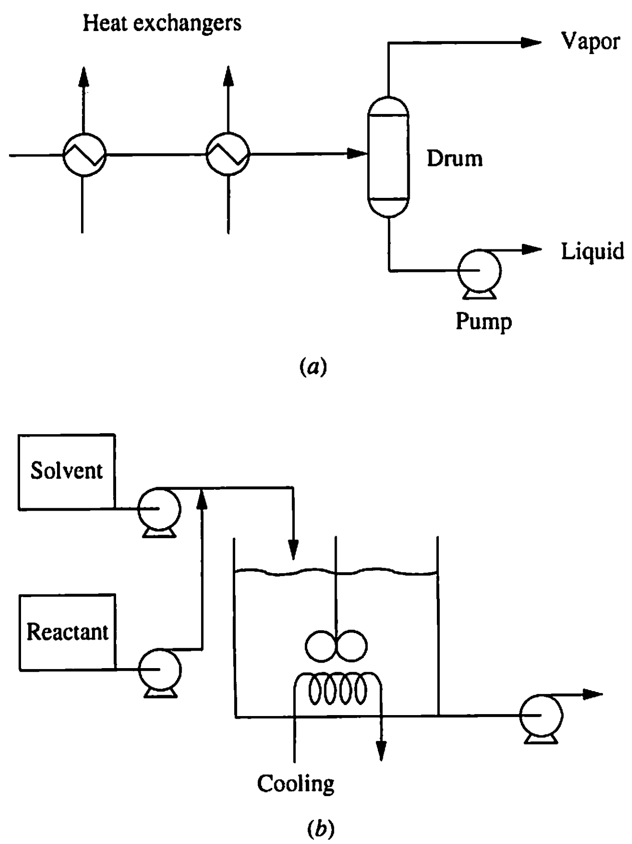
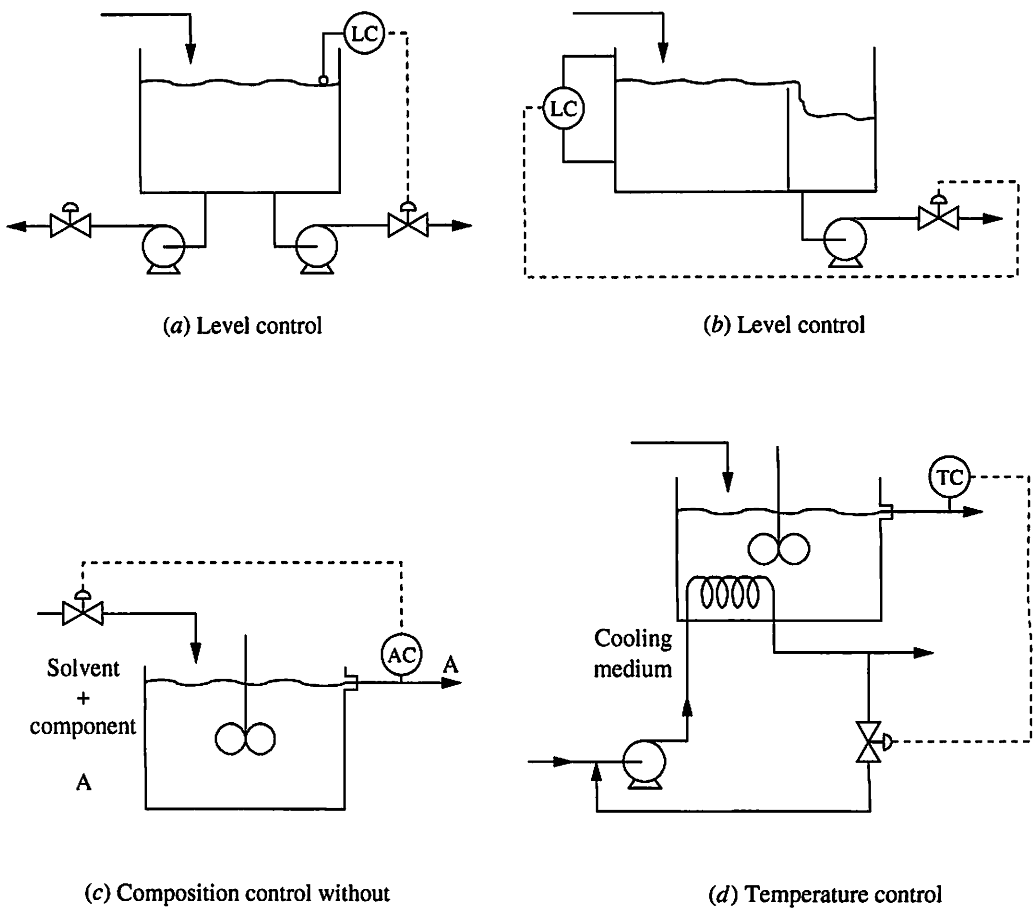


FIGURE Q1.6

1.7. Consider any of the control systems shown in Figure 1.7*a* through *d*. Suggest a feedback control calculation that can be used to determine the proper value of the manipulated valve position. The only values available for the calculation are the desired value and the measured value of the controlled variable. (Do the best you can at this point. Control algorithms for feedback control are presented in Part III.)

1.8. Feedback control uses measurement of a system output variable to determine the value of a system input variable. Suggest an alternative control approach that uses a measured (disturbance) input variable to determine the value of a different (manipulated) input variable, with the goal of maintaining a system output variable at its desired value. Apply your approach to one of the systems in Figure 1.7. Can you suggest a name for your approach?

1.9. Evaluate the potential feedback control designs in Figure Q1.9. Determine whether each is a feedback control system. Explain why or why not, and explain whether the control system will function correctly as shown for disturbances and changes in desired value.



(*a*) Level control

(*b*) Level control

(*c*) Composition control without chemical reaction

(*d*) Temperature control

FIGURE Q1.9