Tikrit University

College of Petroleum Processes Engineering

Petroleum Systems Control Engineering Department

Petroleum Systems Control

Lecture 1

"Introduction to Petroleum Systems Control"

By

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Week1

CHAPTER 1

INTRODUCTORY CONCEPTS

In this chapter we examine the concept of chemical process control and introduce several examples to illustrate the necessity for process modeling as we begin our study of process dynamics and control.

1.1 WHY PROCESS CONTROL?

As competition becomes stiffer in the chemical marketplace and processes become more complicated to operate, it is advantageous to make use of some form of automatic control. Automatic control of a process offers many advantages, including

- Enhanced process safety
- Satisfying environmental constraints
- Meeting ever-stricter product quality specifications
- More efficient use of raw materials and energy
- Increased profitability

Considering all the benefits that can be realized through process control, it is well worth the time and effort required to become familiar with the concepts and practices used in the field.

1.2 CONTROL SYSTEMS

Control systems are used to maintain process conditions at their desired values by manipulating certain process variables to adjust the variables of interest. A common example of a control system from everyday life is the cruise control on an automobile. The purpose of a cruise control is to maintain the speed of the vehicle (the controlled variable) at the desired value (the set point) despite variations in terrain, hills, etc.

(disturbances) by adjusting the throttle, or the fuel flow to the engine (the manipulated variable). Another common example is the home hot water heater. The control system on the hot water heater attempts to maintain the temperature in the tank at the desired value by manipulating the fuel flow to the burner (for a gas heater) or the electrical input to the heater in the face of disturbances such as the varying demand on the heater early in the morning, as it is called upon to provide water for the daily showers. A third example is the home thermostat. This control system is designed to maintain the temperature in the home at a comfortable value by manipulating the fuel flow or electrical input to the furnace. The furnace control system must deal with a variety of disturbances to maintain temperature in the house, such as heat losses, doors being opened and hopefully closed, and leaky inefficient windows. The furnace must also be able to respond to a request to raise the desired temperature if necessary. For example, we might desire to raise the temperature by 5°, and we'd like the system to respond smoothly and efficiently. From these examples, we can deduce that there are several common attributes of control systems:

- The ablity to maintain the process variable at its desired value in spite of disturbances that might be experienced (this is termed *disturbance rejection*)
- The ability to move the process variable from one setting to a new desired setting (this is termed *set point tracking*)

Conceptually we can view the control systems we've discussed in the following general manner (Fig. 1–1).

The controller compares the measurement signal of the controlled variable to the set point (the desired value of the controlled variable). The difference between the two values is called the *error*.

$$\text{Error} = (\text{Set point value}) - (\text{Measurement signal of controlled variable})$$

Depending upon the magnitude and sign of the error, the controller takes appropriate action by sending a signal to the final control element, which provides an input to the process to return the controlled variable to the set point. The concept of using information

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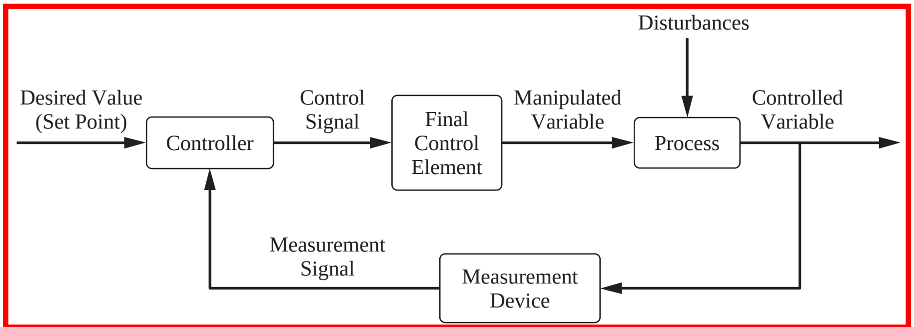

FIGURE 1–1
Generalized process control system.

about the deviation of the system from its desired state to control the system is called *feedback* control. Information about the state of the system is "fed back" to a controller, which utilizes this information to change the system in some way.

The type of control system shown in Fig. 1–1 is termed a *closed-loop* feedback control system. *Closed-loop* refers to the fact that the controller automatically acts to return the controlled variable to its desired value. In contrast, an *open-loop* system would have the measurement signal disconnected from the controller, and the controller output would have to be manually adjusted to change the value of the controlled variable. An open-loop system is sometimes said to be in manual mode as opposed to automatic mode (closed-loop). Negative feedback is the most common type of signal feedback. *Negative* refers to the fact that the error signal is computed from the difference between the set point and the measured signal. The *negative* value of the measured signal is "fed back" to the controller and added to the set point to compute the *error*.

Example 1.1. Hot water tank control system. As a specific example, let us consider a hot water heater for a home (Fig. 1–2) and examine its control system, using the same type of diagram (Fig. 1–3).

The desired hot water temperature is selected by the homeowner, and typically it is in the neighborhood of 120 to 140°F. Let us assume that the set point is 130°F. The thermocouple measures the temperature of the water in the tank and sends a signal to the thermostat indicating the temperature. The thermostat (controller) determines the error as

Thermocouple is a temperature sensor

$$\text{Error} = T_{\text{set point}} - T_{\text{measured}}$$

If the error is positive (> 0), the measured temperature is lower than desired and the thermostat opens the fuel valve to the burner which adds heat to the tank. If the error is zero or negative (≤ 0), the thermostat closes the fuel valve and no heat is added to the tank. Disturbances to the system, which decrease the temperature of the water in the tank, include ambient heat losses and hot water demand by the household which is replaced with a cold water feed.

On/Off control

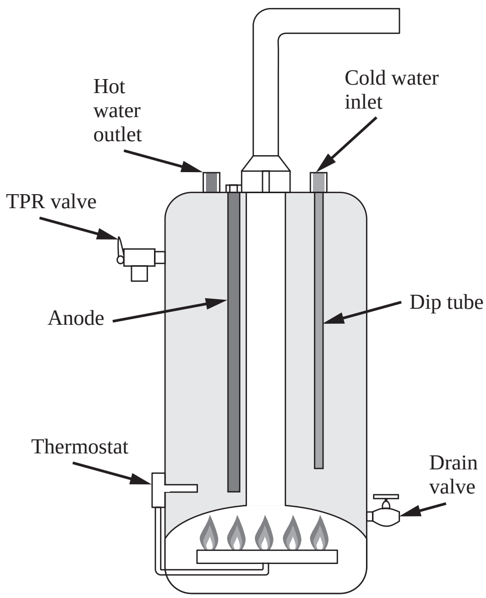

FIGURE 1–2
Physical drawing of a hot water heater.

Types of Controllers

The thermostat on the hot water heater is called an "on/off" type of controller. Depending on the value of the error signal, the output from the controller is

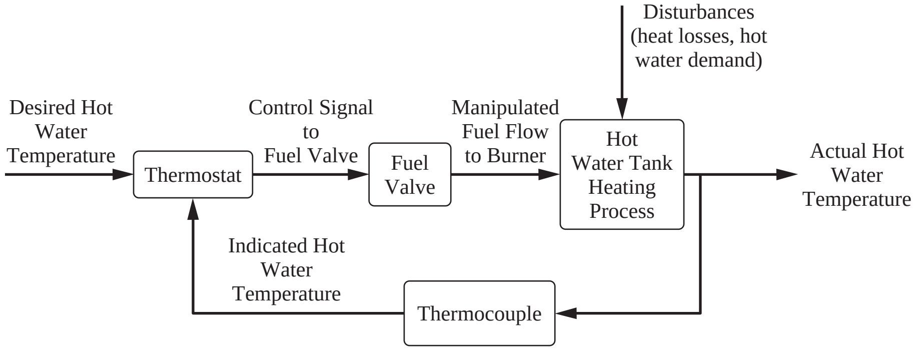

FIGURE 1–3
Block diagram of a hot water heater control system.

either "full on" or "full off" and the fuel valve is full open or full closed; there are no intermediate values of the output. Many other types of controllers that we will study can modulate their output based on the magnitude of the error signal, how long the error signal has persisted, and even how rapidly the error appears to be changing.

Clearly, the larger the error, the less we are satisfied with the present state of affairs and vice versa. In fact, we are completely satisfied only when the error is exactly zero. Based on these considerations, it is natural to suggest that the controller should change the heat input by an amount *proportional* to the error. This is called *proportional control*. In effect, the controller is instructed to maintain the heat input at the steady-state design value as long as the error is zero. If the tank temperature deviates from the set point, causing an error, the controller is to use the magnitude of the error to change the heat input proportionally. We shall reserve the right to vary the proportionality constant to suit our needs. This degree of freedom forms a part of our instructions to the controller. As we will see shortly during the course of our studies, the larger we make the proportionality constant for the proportional controller (called the controller gain), the smaller the steady-state error will become. We will also see that it is impossible to completely eliminate the error through the use of a proportional controller. For example, if the set point is 130°F and a disturbance occurs that drops the temperature to 120°F, if we use only a proportional controller, then we will never be able to get the tank temperature to *exactly* 130°F. Once the sytem stabilizes again, the temperature will not be exactly 130°F, but perhaps 127°F or 133°F. There will always be some residual steady-state error (called *offset*). For a home water heater, this is probably good enough; the exact temperature is not that critical. In an industrial process, this may not be adequate, and we have to resort to a bit more complicated controller to drive the error to zero.

But what about the value of the control input??

Considerable improvement may be obtained over proportional control by adding integral control. The controller is now instructed to change the heat input by an additional amount proportional to the time integral of the error. This type of control system has two adjustable parameters: a multiplier for the error and a multiplier for the integral of the error. If this type of controller is used, the steady-state error will be zero. From this standpoint, the response is clearly superior to that of the system with proportional control only. One price we pay for this improvement is the tendency for the system to be more

drawback of PI Control

oscillatory. The system will tend to overshoot its final steady-state value before slowly settling out at the desired set point. So what is the best control system to use for a particular application? This and related questions will be addressed in subsequent chapters.

To eliminate the overshoot add derivative control to construct PID controller which is widely used in industrial applications

Some Further Complications

At this point, it would appear that the problem has been solved in some sense. A little further probing will shatter this illusion.

It has been assumed that the controller receives instantaneous information about the tank temperature. From a physical standpoint, some measuring device such as a thermocouple will be required to measure this temperature. The temperature of a thermocouple inserted in the tank may or may not be the same as the temperature of the fluid in the tank. This can be demonstrated by placing a mercury thermometer in a beaker of hot water. The thermometer does not instantaneously rise to the water temperature. Rather, it takes a bit of time to respond. Since the controller will receive measured values of the temperature, rather than the actual values, it will be acting upon the *apparent error*, rather than the actual error. The effect of the thermocouple delay in transmission of the temperature to the controller is primarily to make the response of the system somewhat more oscillatory than if the response were instantaneous. If we increase the controller gain (the proportionality constants), the tank temperature will eventually oscillate with *increasing* amplitude and will continue to do so until the physical limitations of the heating system are reached. In this case, the control system has actually caused a deterioration in performance, and this type of reponse is referred to as an *unstable response.*

Why the mercury thermometer is added as monitoring device?

Explain the apparent error??

This problem of *stability* of response will be a major concern for obvious reasons. At present, it is sufficient to note that extreme care must be exercised in specifying control systems. In the case considered, the proportional and integral controllers described above will perform satisfactorily if the gain is kept lower than some particular value. However, it is not difficult to construct examples of systems for which the addition of *any* amount of integral control will cause an unstable response. Since integral control usually has the desirable feature of eliminating steady-state error, it is extremely important that we develop means for predicting the occurrence of unstable response in the design of any control system.

Block Diagram

A good overall picture of the relationships among variables in the heated-tank control system may be obtained by preparing a *block diagram* as shown in Fig. 1–1. It indicates the flow of information around the control system and the function of each part of the system. Much more will be said about block diagrams later, but the reader can undoubtedly form a good intuitive notion about them by comparing Fig. 1–1 with the physical description of the process. Particularly significant is the fact that each component of the system is represented by a block, with little regard for the actual physical characteristics of the represented component (e.g., the tank or controller). The major interest is in (1) the relationship between the signals entering and leaving the block and (2) the manner in which information flows around the system.

Main idea of Block Diagram

CHAPTER
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CAPSULE SUMMARY

DEFINITIONS

Block diagram—Diagram that indicates the flow of information around the control system and the function of each part of the system.

Closed loop—In closed loop, the measured value of the controlled variable is fed back to the controller.

Controlled variable—The process variable that we want to maintain at a particular value.

Controller—A device that outputs a signal to the process based on the magnitude of the error signal. A *proportional* controller outputs a signal proportional to the error.

Disturbance rejection—One goal of a control system, which is to enable the system to "reject" the effect of disturbance changes changes and maintain the controlled variable at the set point.

Disturbances—Any process variables that can cause the controlled variable to change. In general, disturbances are variables that we have no control over.

Error—The difference between the values of the set point and the measured variable.

Manipulated variable—Process variable that is adjusted to bring the controlled variable back to the set point.

Negative feedback—In negative feedback, the error is the difference between the set point and the measured variable (this is usually the desired configuration).

Offset—The steady-state value of the error.

Open loop—In open loop, the measured value of the controlled variable is not fed back to the controller.

Positive feedback—In positive feedback, the measured temperature is added to the set point. (This is usually an undesirable situation and frequently leads to instability.)

Set point—The desired value of the controlled variable.

Set point tracking—One goal of a control system, which is to force the system to follow or "track" requested set point changes.