MODULE TITLE : CONTROL SYSTEMS AND AUTOMATION

TOPIC TITLE : CONTROL DEVICES AND SYSTEMS

LESSON 3 : COMPLEX CONTROL SYSTEMS

CSA - 4 - 3

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INTRODUCTION

So far, we have only dealt with control loops designed to control one variable, regardless of other process parameters. There are, however, many industrial situations in which several system variables can affect the performance of a single variable controller. This lesson discusses methods of overcoming this type of complex problem.

YOUR AIMS

On completion of this lesson you should be able to:

- appreciate the limitations of simple control systems
- explain with the aid of diagrams how these limitations can be overcome
- give examples of the following types of control techniques:
  - cascade control
  - disturbance feed forward
  - disturbance feedback
  - ratio control.

LIMITATIONS OF SINGLE VARIABLE CONTROL SYSTEMS

The level indicator controller, LIC 1, shown in FIGURE 1 maintains the fluid level within the tank using a simple feedback loop. The control is effective under normal conditions although the system suffers from some inherent 'lags'.

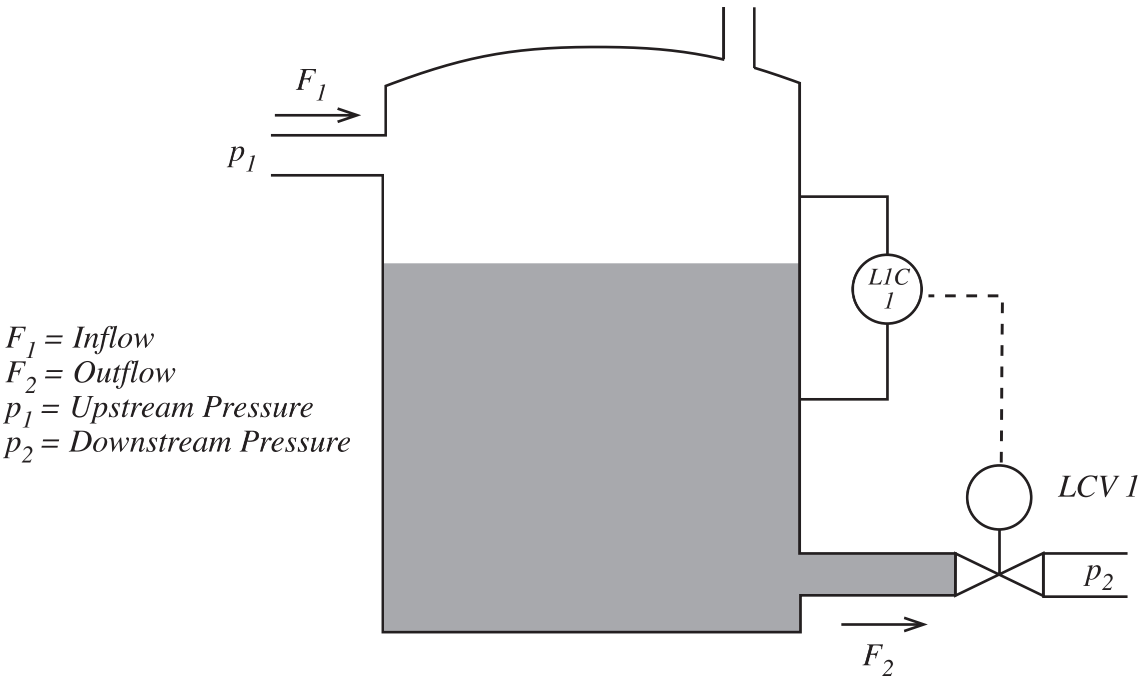

FIG. 1

The fluid level in the tank is maintained by regulating the outflow, F_2. The level will remain constant provided that the flow rates F_1 and F_2 are equal.

If the pressure, p_2, downstream of the vessel changes, the outflow F_2 will change and the level will be affected. For example, given a fall in p_2, the pressure drop across the valve will increase causing F_2 to increase. Assuming that the flow rate F_1 remains constant, F_2 will exceed F_1 resulting in a fall in level. The level controller must detect a deviation before it can produce corrective action.

The speed at which the deviation develops depends on the difference between F_1 and F_2 and on the capacity of the vessel. The larger the capacity of the vessel, the more slowly the deviation will develop.

A time lag occurs during the development of the deviation and a second one occurs as the corrective action comes into effect. The combined effect of these two lags may result in a slow system response.

The most significant time lag occurs because the level controller is only responsive to changes in level and not to changes in flow. One obvious way to improve the speed of response is to link 'together' the fluid level and flow rate variables.

COMPOUND VARIABLE CONTROL LOOPS

CASCADE CONTROL

One method of linking two variables together is employed in cascade control. In this technique the set-point of one control variable is determined by the measured value of a second variable. We can illustrate this by modifying our previous control loop as shown in FIGURE 2.

The level controller has a manually adjustable set point. Its output, which previously operated the valve, now provides the set point for the flow controller. The flow controller output now operates the valve which controls the tank outflow F_2.

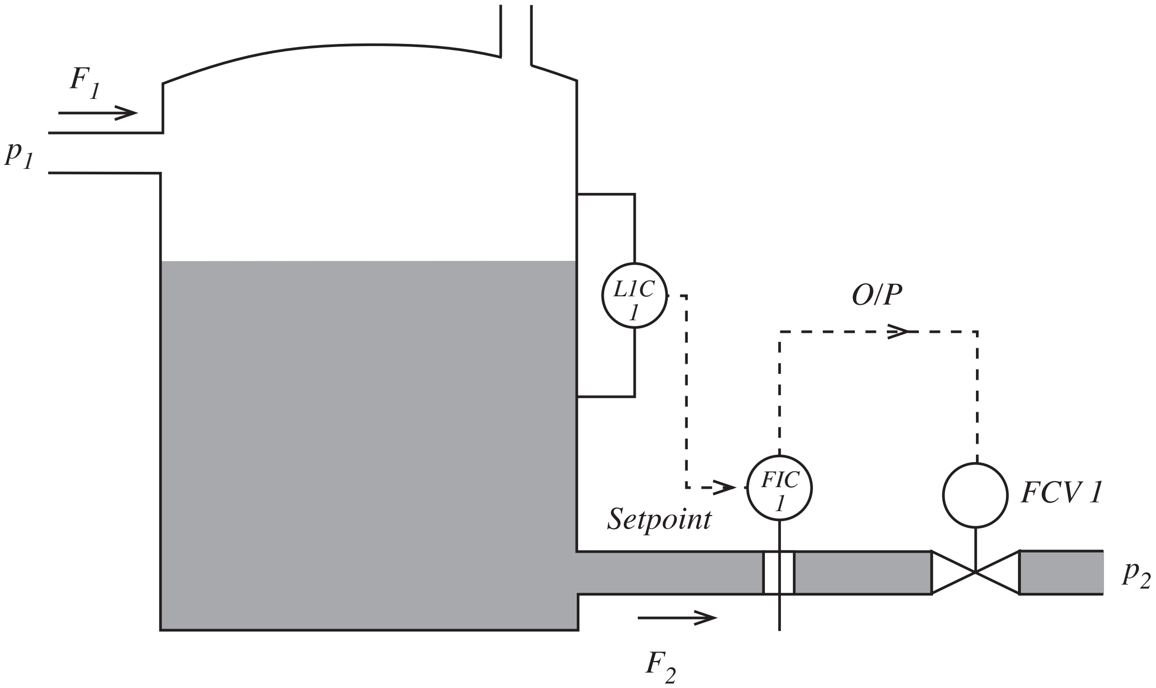

FIG. 2

If the outflow F_2 changes it is detected by the flow controller and rectified before it can affect the level of liquid in the vessel.

Because the level controller dictates the set point setting to the flow controller, it is known as the *master* or *primary controller* and the flow controller is known as the *slave* or *secondary controller*.

As mentioned earlier, this type of control is known as cascade control and we say that "the level or master controller is cascaded onto the flow or slave controller." For this type of system to be successful, the slave control loop must have a faster response than the master controller. In our system, the flow control loop will have a shorter response time than the level control loop.

The cascade control loop is shown schematically in FIGURE 3.

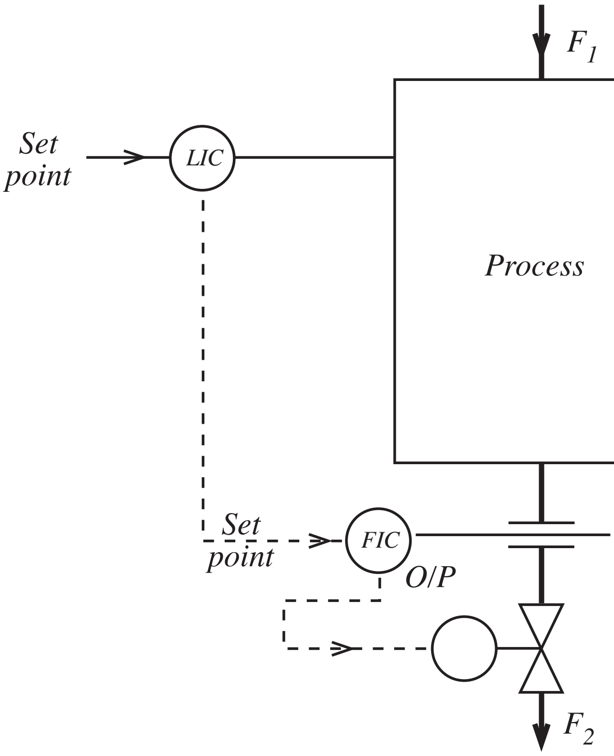

FIG. 3

DISTURBANCE FEEDFORWARD

The cascade system shown in FIGURE 2, responds to any disturbances within or downstream of the vessel. However a disturbance occurring upstream and affecting the flow rate F_1 would alter the level within the tank before any corrective action could take place.

Disturbance feed forward control monitors the upstream conditions and feeds them forward in order to correct for any anticipated change before it occurs. FIGURE 4 shows how this is achieved.

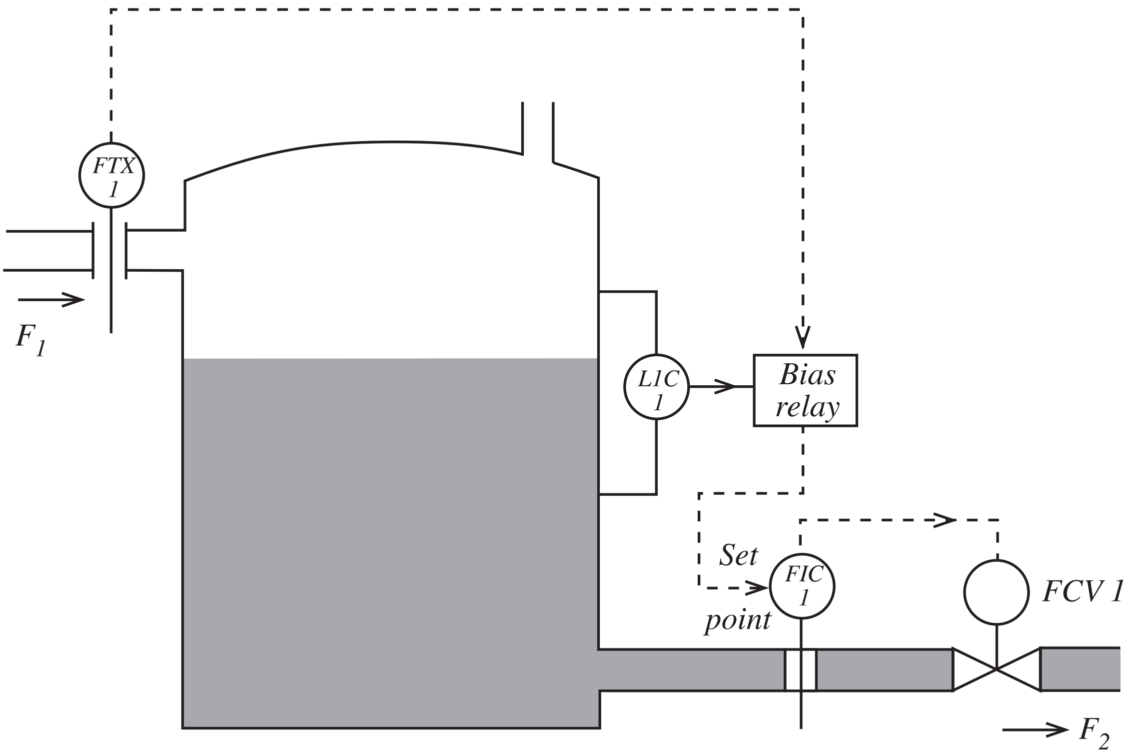

FIG. 4

The master controller LIC 1 maintains the level of liquid in the vessel by continuously regulating the liquid outflow F_2. However, if the input flow rate changes the new value of F_1 is fed forward to the bias relay. The output of the bias relay changes by an identical amount, modifies the flow controller set point accordingly and changes the out flowing liquid flow rate, F_2, to match the new value of F_1. Thus a potential change in level is avoided by maintaining the balance between F_1 and F_2.

The system is now self accommodating for disturbances upstream and downstream of the vessel.

DISTURBANCE FEEDBACK CONTROL

An alternative strategy is to regulate the liquid flowing into the tank and cascade the level controller to it. In addition, we can also monitor the outflow rate F_2 and feed this signal back via a bias relay. FIGURE 5 illustrates this type of control loop applied to the level control system.

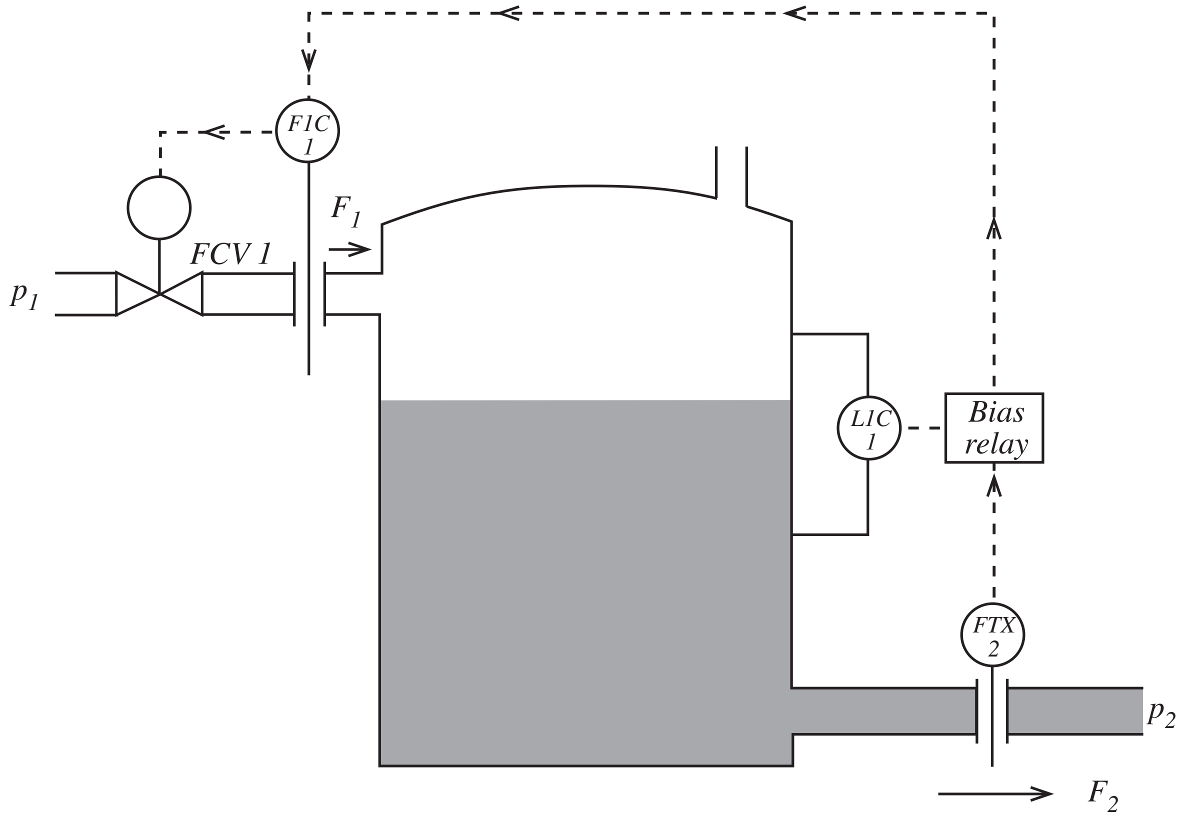

FIG. 5

See if you can describe the operation of the disturbance feedback control system shown in FIGURE 5.

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The master controller LIC 1 maintains the liquid level in the vessel by continuously regulating the inflow rate F_1. If the outflow rate changes, the new value of F_2 is fed back to the bias relay. The output of the bias relay modifies the flow controller set point and changes the inflowing liquid flow rate F_1 to match the new F_2 value.

RATIO CONTROL

In some cases a single control loop is used to control the relationship between two or more separate variables. The most common example of this is **ratio control**.

Fixed Ratio Control

Ratio control allows for the mixing of two process products in pre-defined quantities. The simplest form of ratio control occurs when a variable signal is multiplied by a fixed factor to provide an output which is proportional to the signal.

A simple example of a fixed ratio control system is shown in FIGURE 6. Ammonia is made by passing hydrogen and nitrogen in a fixed ratio through a catalyst bed. The ratio is one part of nitrogen to three parts of hydrogen.

In all ratio control systems, we have two variables, one of which is called the *controlled* variable and the other the *wild* variable. A wild variable is one which is in short supply or can fluctuate widely because of the production process. In our example, hydrogen is the wild variable whose flow is measured and transmitted to the input side of the ratio unit whose pre-set ratio factor is one third.

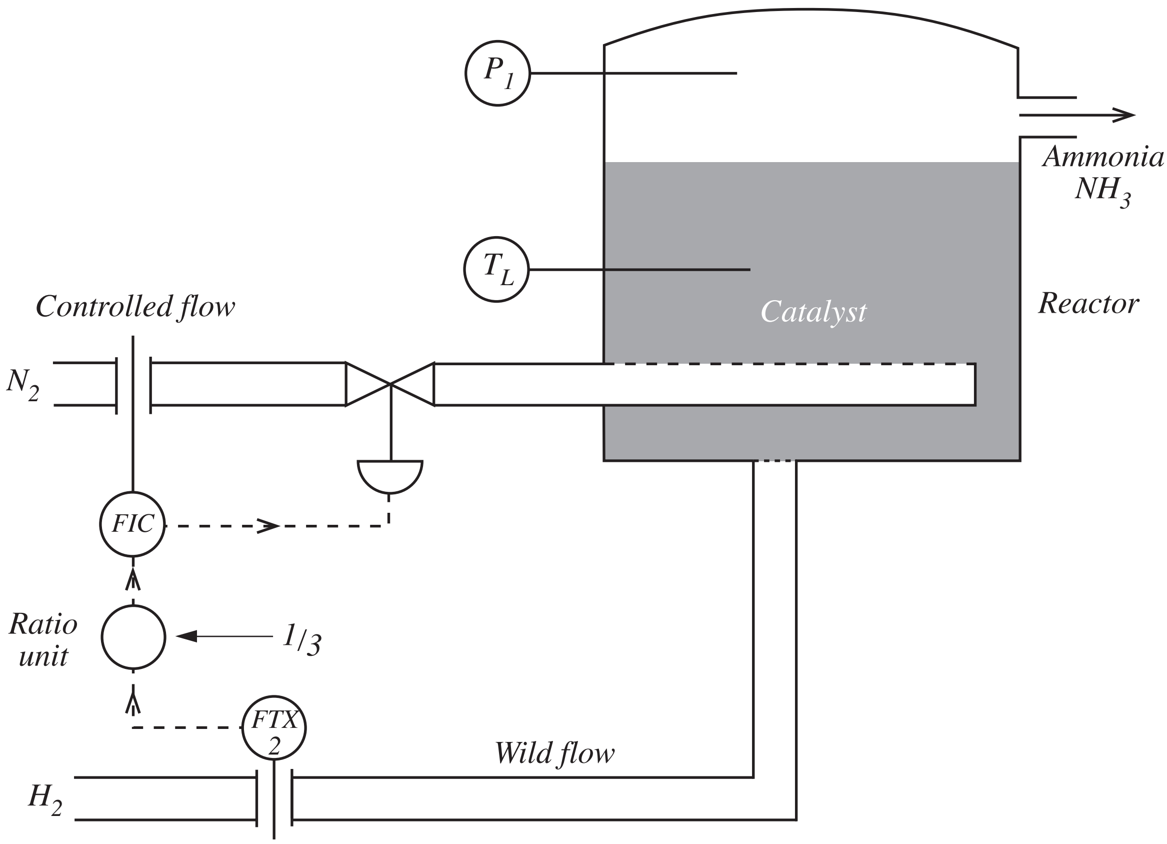

FIG. 6 Fixed ratio control

The hydrogen flow signal is, therefore, multiplied by a factor of one third, after correction for the live zero, and then becomes the set point input of the controlled variable flow controller. Hence, the nitrogen flow rate is maintained at one third of the uncontrolled hydrogen flow rate.

Variable Ratio Control System

In some systems, two variables are required to be mixed according to a variable ratio. An example of such a system is illustrated in FIGURE 7.

In this process the alkali must be added in a fixed ratio to neutralise the waste acid. However, if the initial strength of the acid changes, the ratio of the acid to alkali addition must be changed. This is achieved by monitoring the pH of the mixed solution and feeding a signal back which becomes the set point of the ratio control unit.

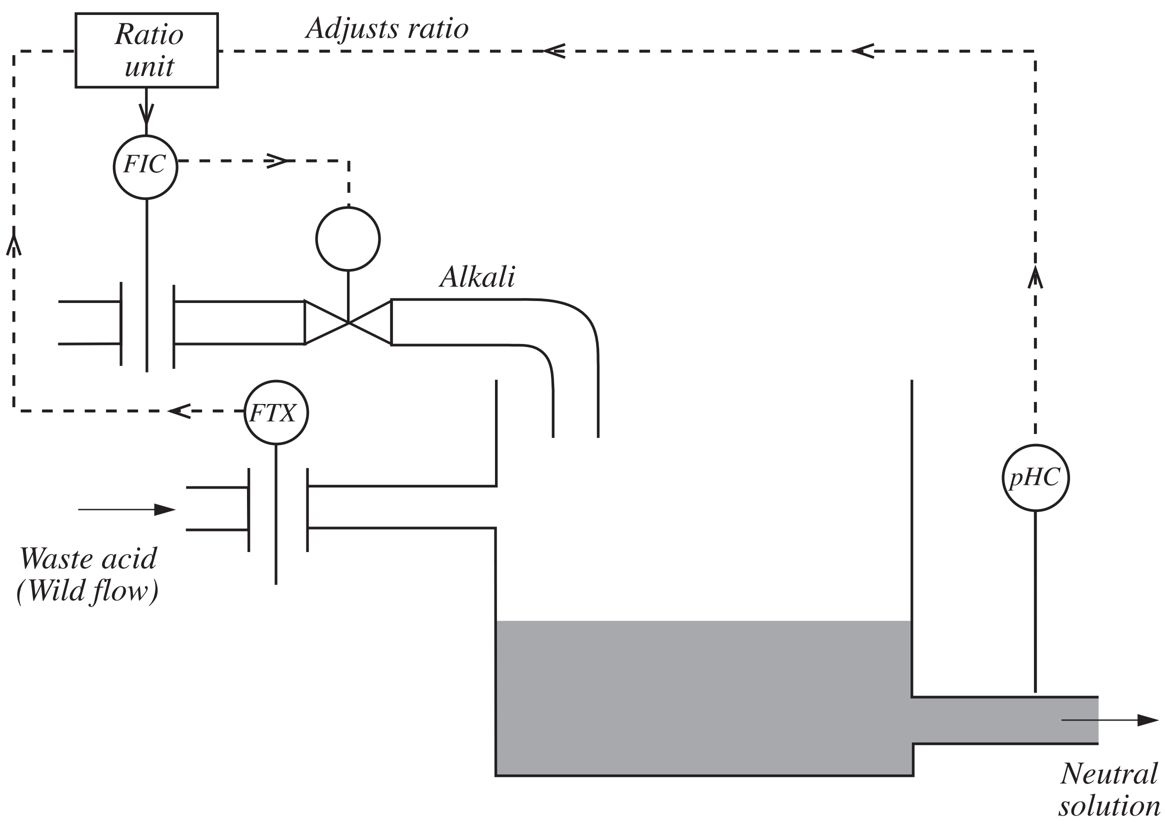

FIG. 7

Now attempt the following Self-Assessment Questions.

NOTES

SELF-ASSESSMENT QUESTIONS

1. FIGURE 8 shows a steam coil heater used to raise the temperature of a liquid. It is required to maintain a constant liquid exit temperature by controlling the steam flow. Show how this may be achieved using a simple control system.

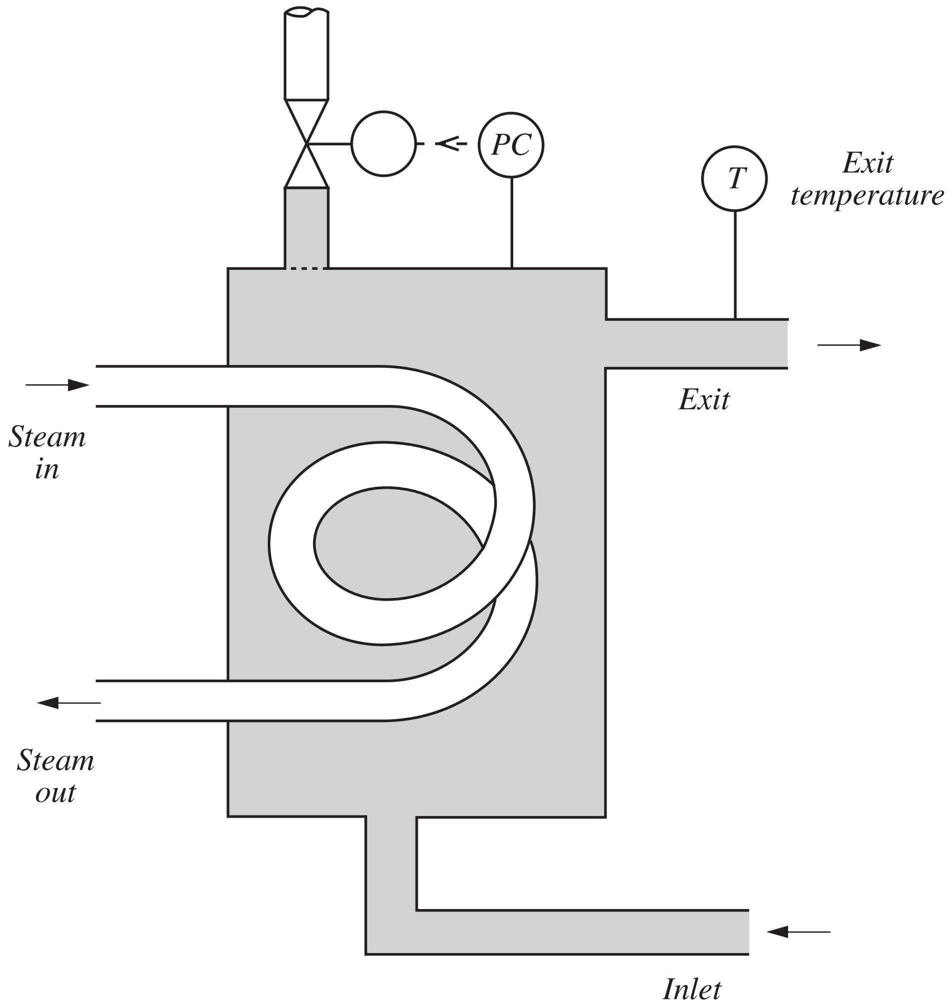

FIG. 8

2. The exit temperature is still variable and difficult to control, because the steam pressure is not constant. Show by means of a sketch how this problem may be overcome using cascade control.

3. With cascade control the exit temperature remains stable, but when the plant is starting up or shutting down the inlet flow varies. Show how the use of disturbance feed forward control can compensate for variations in inlet flow and maintain a constant exit temperature.

ANSWERS TO SELF-ASSESSMENT QUESTIONS

1. A simple temperature control system is shown in FIGURE 9.

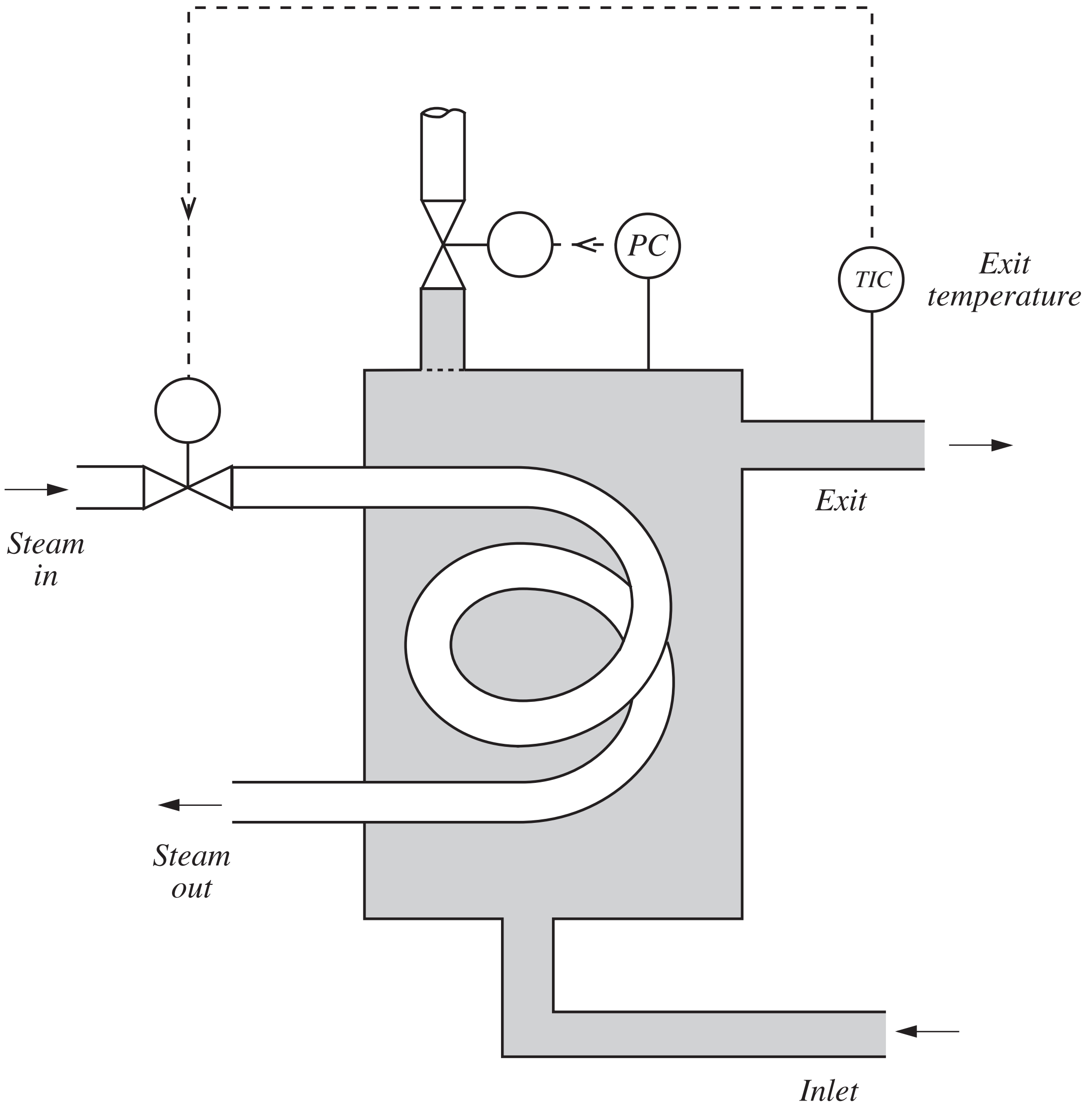

FIG. 9

2. The cascade modification is shown in FIGURE 10.

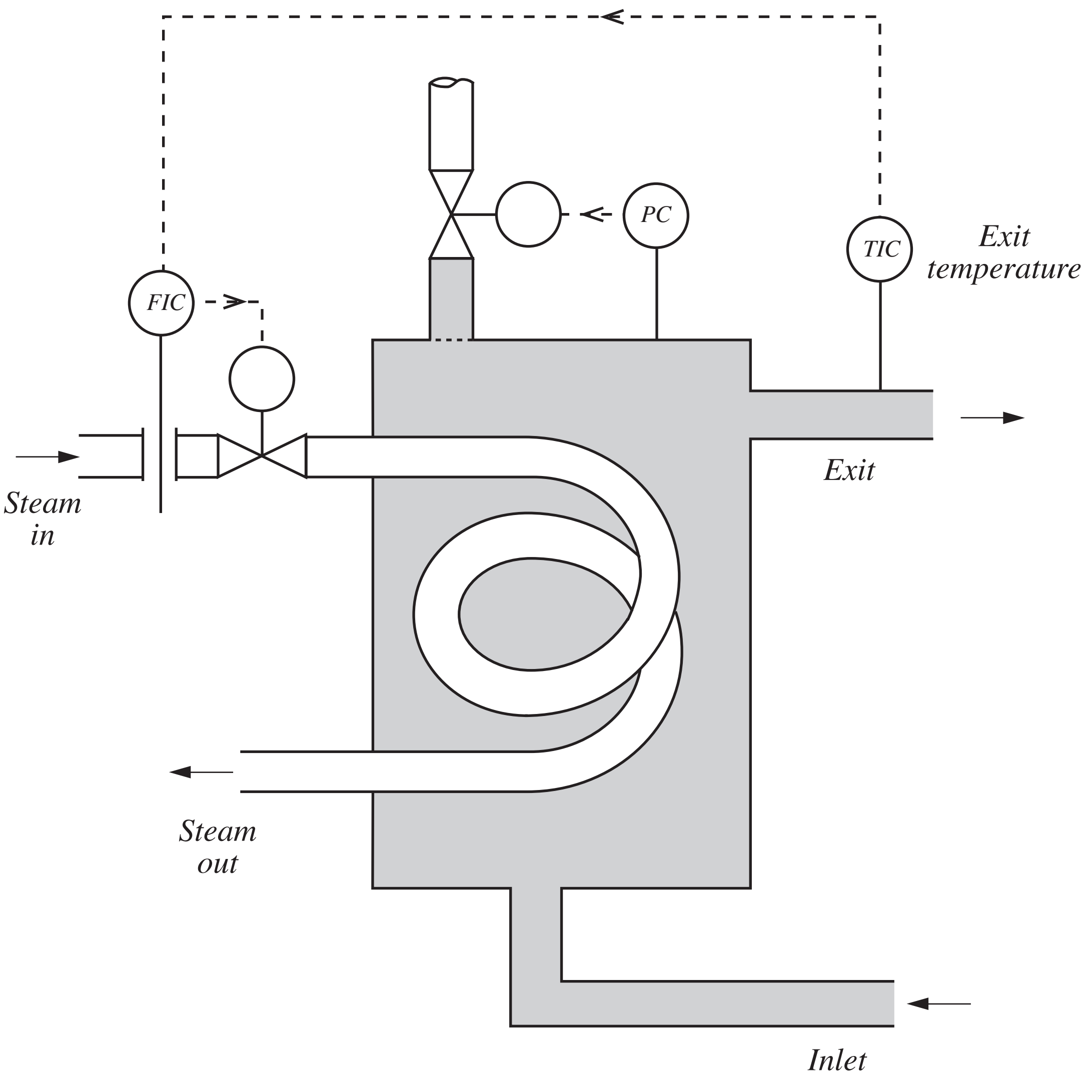

FIG. 10

3. The final modification to the system is as shown in FIGURE 11.

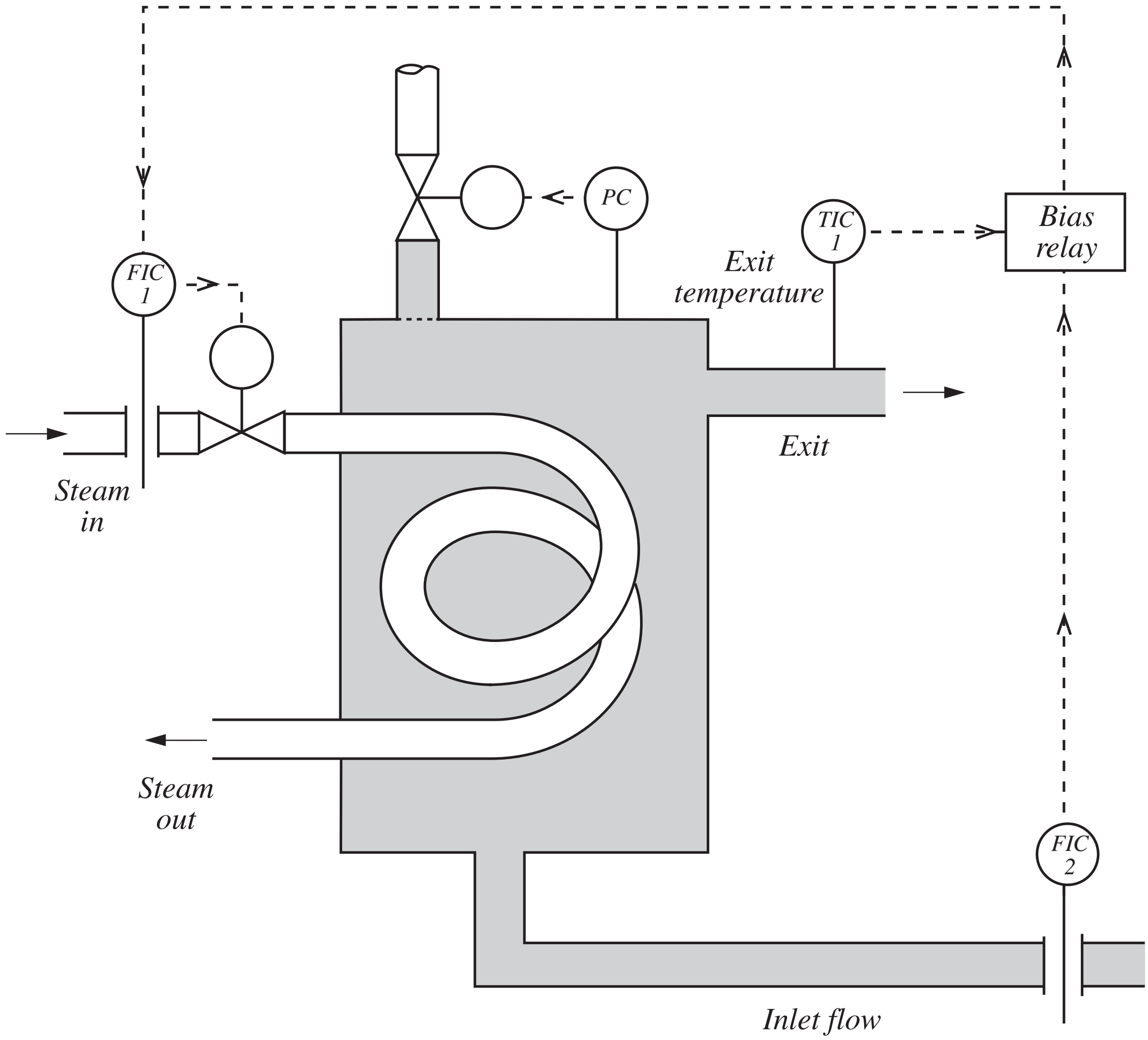
FIC
1
PC
TIC
1
Bias
relay
Exit
temperature
Exit
Steam
in
Steam
out
FIC
2
Inlet flow

FIG. 11

SUMMARY

- A simple control loop which often provides adequate control for a single variable process may be slow to respond to changes which occur in processes possessing inherent time delays.

- Cascade control is used to control a 'secondary' variable which will affect the main variable we are attempting to control. Corrective action is, therefore, taken in anticipation of changes to the main variable.

- Systems involving more than one secondary variable may require disturbance feedback or disturbance feed forward control action in association with cascade control.

- Fixed ratio control can be adopted when two variables must be controlled in a fixed ratio and other related system parameters remain constant. However, if a related parameter is subject to variation a variable ratio control system will be required.