Instrumentation and Process control

(CHE-S306)

Incentives for chemical process control

A chemical plant must satisfy several requirements imposed by its designers and general technical, economics and social conditions in the presence of ever – changing external influences (disturbances):

- Safety
- Production specification
- Environment regulation
- Operational constraints
- Economics

All the requirements listed dictate the need for continuous monitoring of the operation of the chemical plant and external intervention (control) to guarantee the satisfaction of the operational objectives.

This is accomplished through a rational **arrangement of the equipment**

(Measuring device, valves, controllers, computers)

Human intervention

(Plant designers, plant operators)

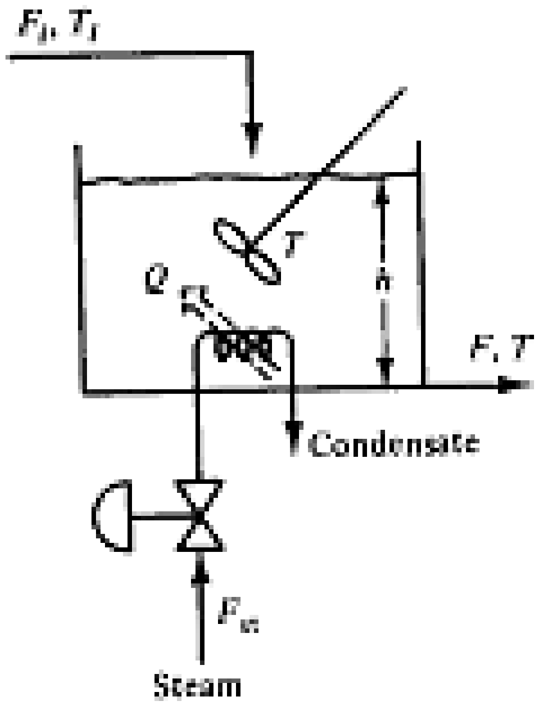
Which together constitute the **control system**

Control system should satisfy

- Suppressing the influence of external disturbances
  - Need to introduce a control mechanism that will make the proper changes on the Process to cancel the negative impact.

- Ensuring the stability of Chemical process
- Optimizing the performance of Chemical process

Controlling the operation of a Stirred tank Heater



Inlet flow rate and Temperature F_i, T_i

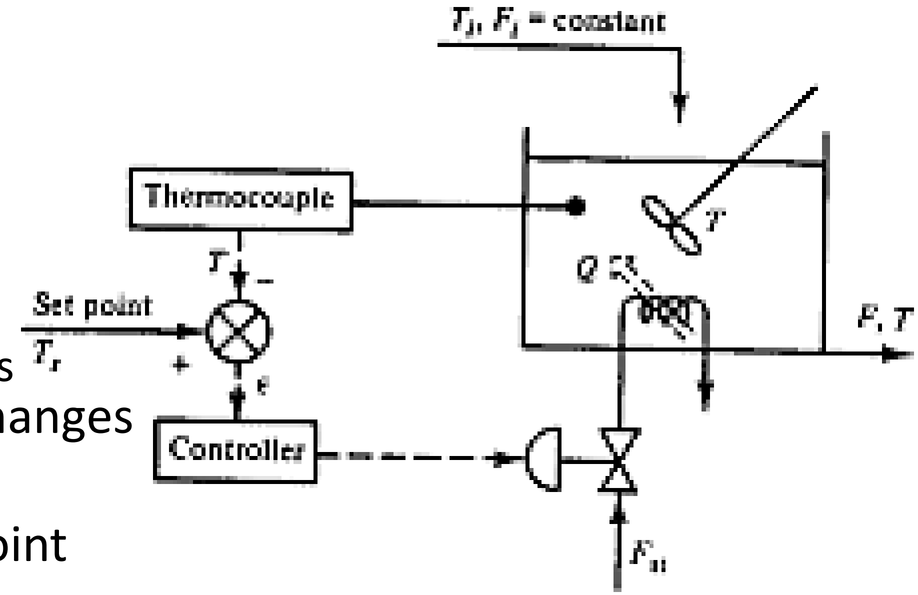
Steam flow rate Fst

Temperature of outlet stream F, T

Disturbance : changes in the inlet F_i, T_i

Final attaining value : T_s and V_s

Feedback control system



Control action to keep T= Ts when T_i of F_i changes

Temperature inside the tank = T

T is compared with desired value= Ts; Set point

Deviation ϵ = Ts- T

The deviation is sent to a control mechanism which decides what must be done in order for

the temperature T to return back to desired value Ts.

If $\epsilon > 0$; Ts > T , The controllers open the steam valve so that more heat can be supplied.

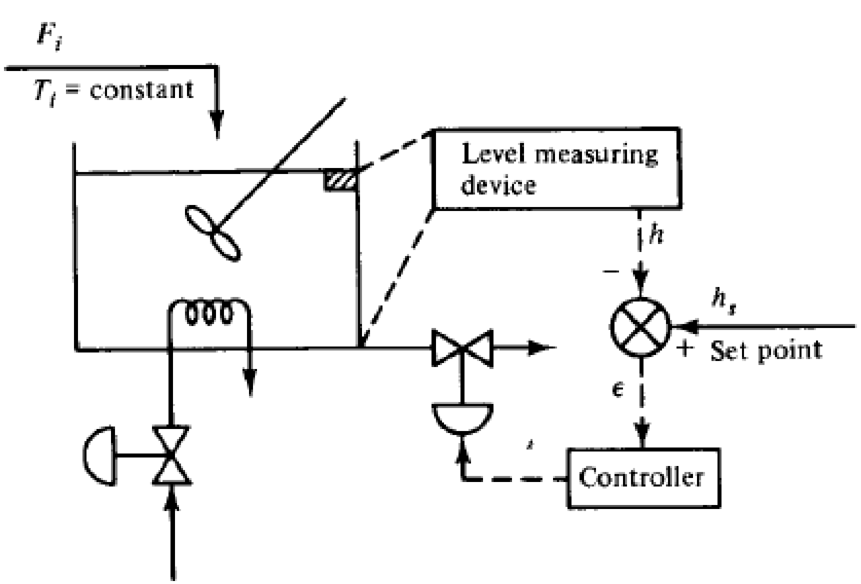
If $\epsilon < 0$; Ts < T , The controllers close the steam valve so no extra heating is required

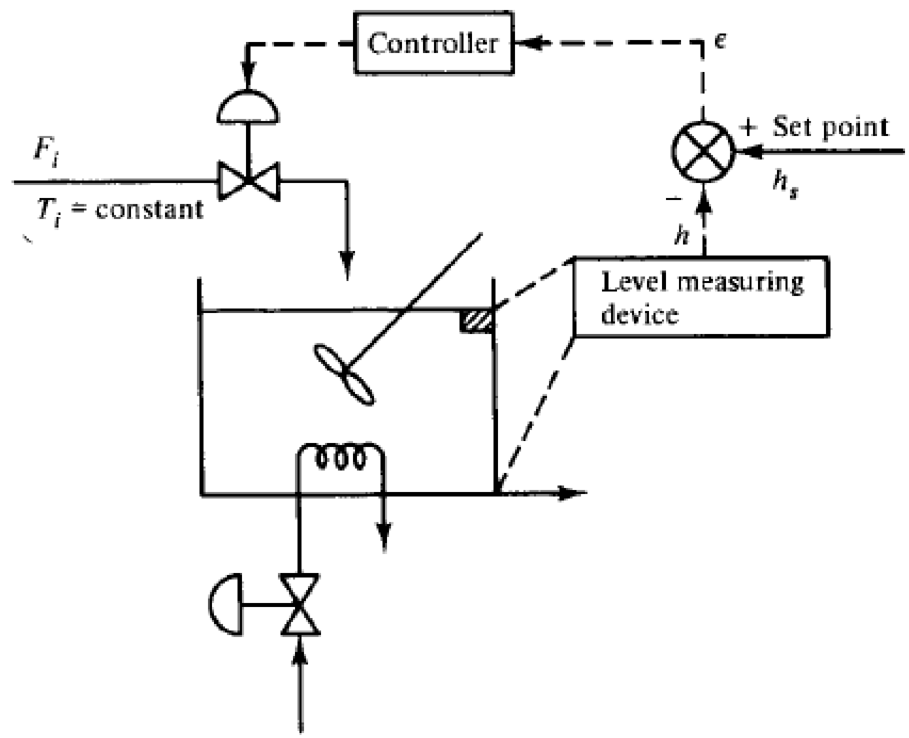
If $\epsilon = 0$; Ts = T, Controller does nothing.

The control system, which measure the variable of direct importance (T) after the disturbance had its effect on it, is called the **Feedback control system**

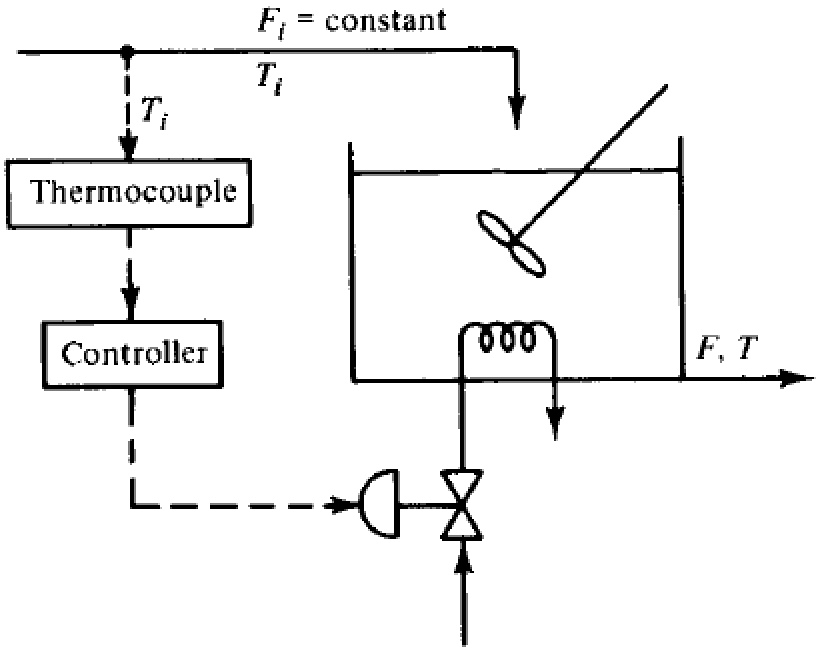
Feedback control system

A similar configuration can be used if we want to keep the volume V, or equivalently the liquid level h, at its set point h_s when F_i changes. In this case we measure the level of the liquid in the tank and we open or close the valve that affects the effluent flow rate F, or inlet flow rate F_i (see Figure 1.3). It is clear that the control systems shown in Figure 1.3 are also feedback control systems. All feedback systems shown in Figures 1.2 and 1.3 act post facto (after the fact), that is, after the effect of the disturbances has been felt by the process.





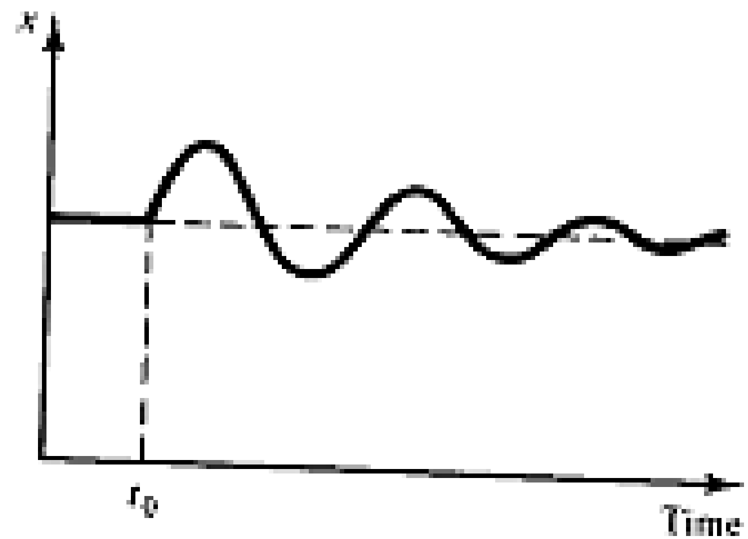
Feed forward system for temperature



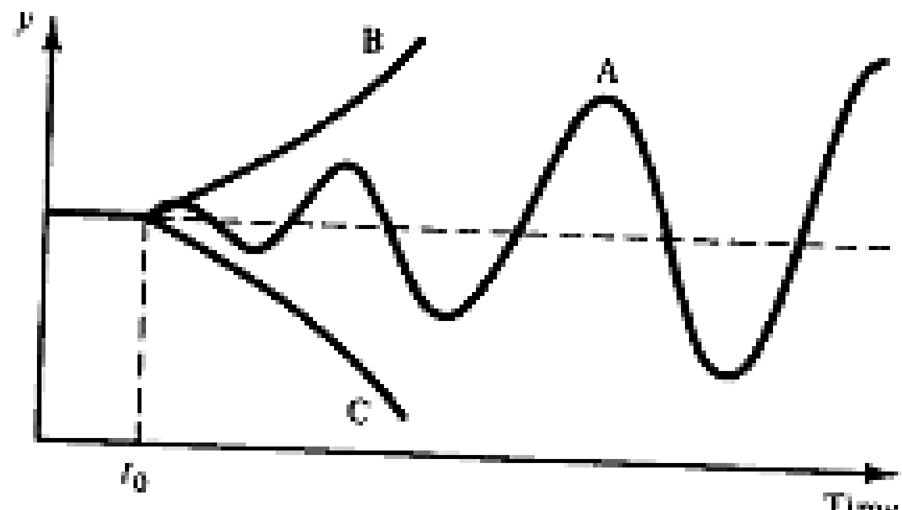
- We can use different control arrangement to maintain T=Ts
- when T_i change Measure the Ti and open / close the steam valve to provide more / less steam
- Forward control does not wait until the effect of the disturbances has been felt by the system

Ensure the stability of a process

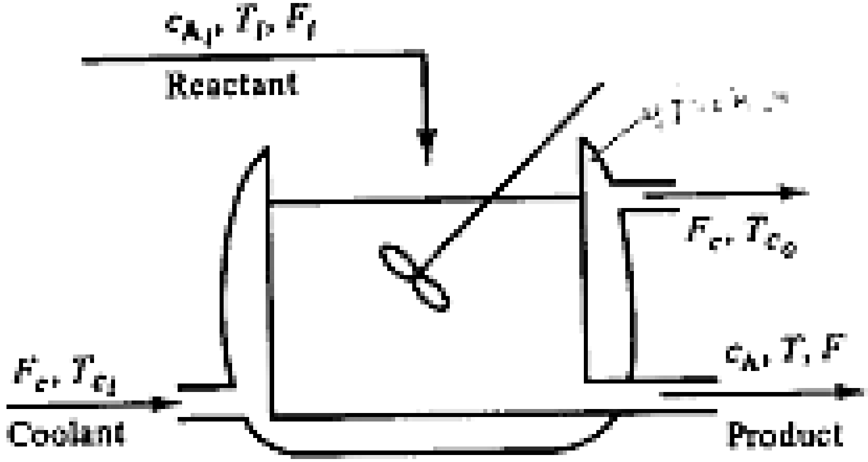
Response of a stable system



Alternative Response of a unstable system



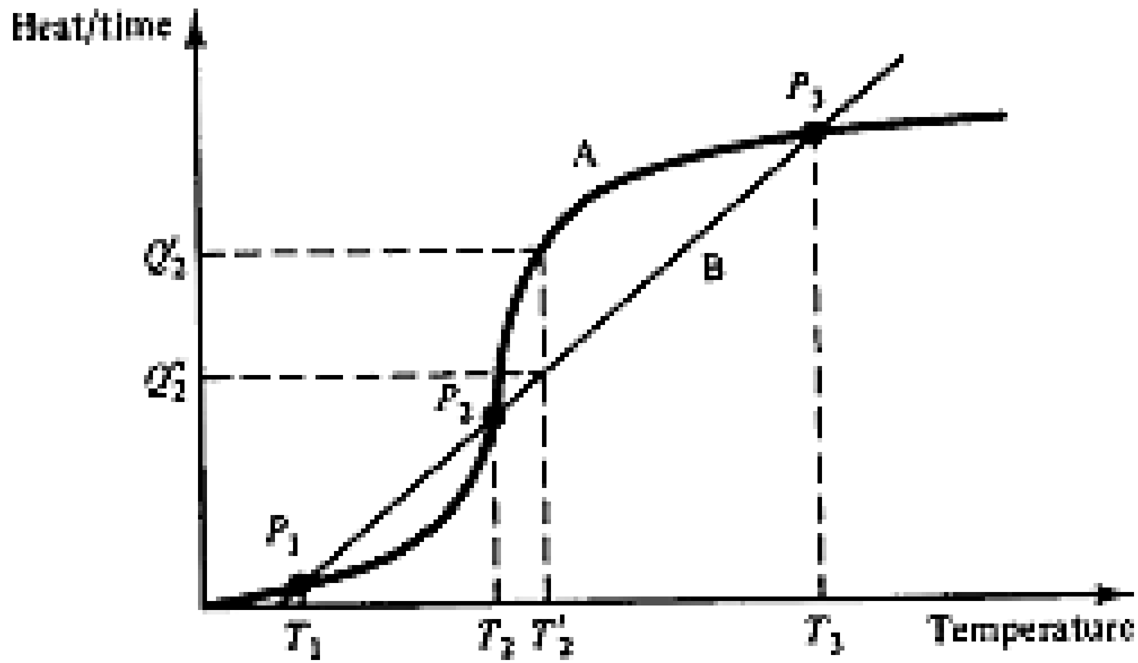
Controlling the operation of unstable system



Irreversible Reaction A→ B
Heat of reaction is removed by the coolant medium that flows through a jacket.

The curve that describes the amount of heat released by the exothermic reaction is a sigmoidal function of the temperature T in the reactor (Curve A).

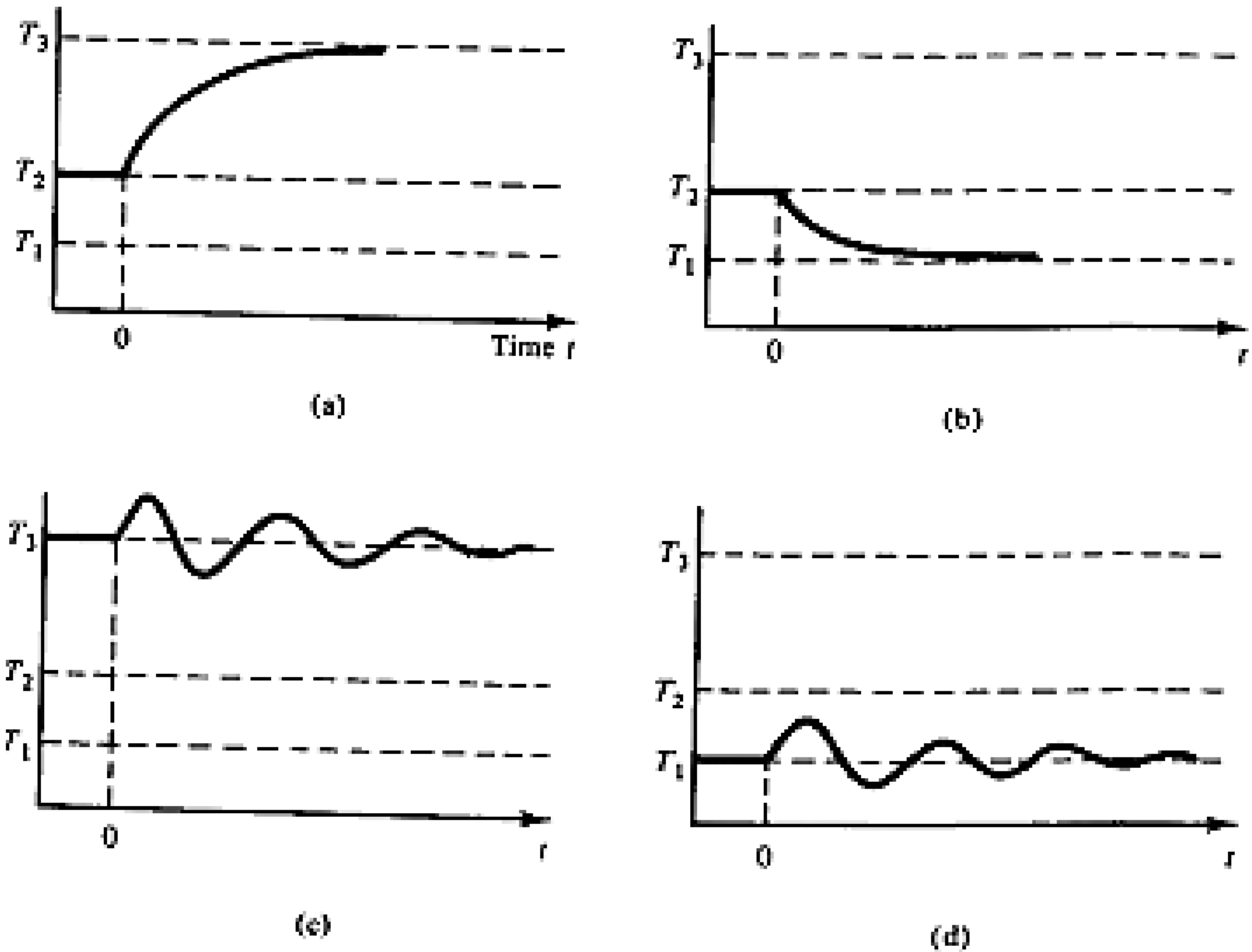
Heat removed by the coolant is a linear function of the temperature T (Line B).



At steady state heat produced by the reaction is equal to heat removed by the coolant.

Point P_1, P_2 and P_3 meet the above condition.

P_1 and P_3 are called stable, whereas P_2 is unstable .



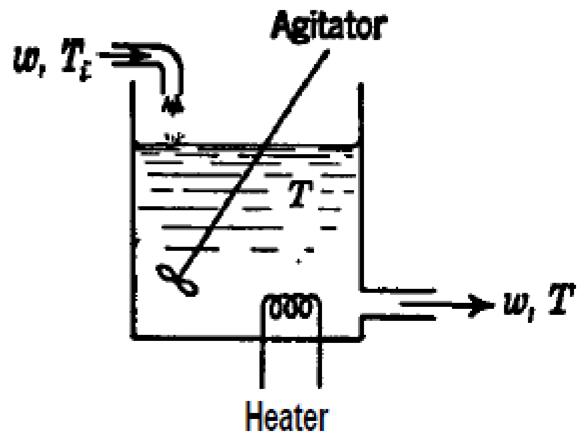
a) and b) indicates the instability of the middle steady state

c) and d) demonstrate the stability of the process

Optimize the Performance of a Chemical Process

- Safety and the satisfaction of production specification are the two principal operational objectives of the Chemical plant.
- Next goal is how to make the operation of the plant more profitable.
- We would like to change the operation of the plant (flow rate, pressure, conc., Temperature)
- This task is undertaken by **automatic controllers** of the plant and its human operators.

System



- A liquid stream at temperature T_i is available at a constant flow rate of w in units of mass per time. It is desired to heat this stream to a higher temperature T_R.
- Heated fluid is removed from the bottom of the tank at the flow rate w as the product of this heating process.
- Under these conditions, the mass of fluid retained in the tank remains constant in time, and the temperature of the effluent fluid is the same as that of the fluid in the tank.
- For a satisfactory design this temperature must be T_R. The specific heat of the fluid C is assumed to be constant, independent of temperature.

Steady-State Design

- A process is said to be at steady state when none of the variables are changing with time.
- At the desired steady state, an energy balance around the heating process may be written as follows:

$$q_s = wC(T_s - T_{i_s})$$

- For a satisfactory design, the steady-state temperature of the effluent stream T_s must equal T_R. Hence

$$q_s = wC(T_R - T_{i_s})$$

- A typical process condition that may change is the inlet temperature, T_i .
- An obvious solution to the problem is to design the heater so that its energy input may be varied as required to maintain T at or near T_R.

Process Control

- It is necessary to decide how much the heat input ***q*** is to be changed from ***qs*** to correct any deviations of *T* from *TR.*
- One solution would be to hire a process operator, who would be responsible for controlling the heating process.
- The operator would observe the temperature in the tank, presumably with a measuring instrument such as a thermocouple or thermometer, and compare this temperature with T_R. If T were less than T_R, he would increase the heat input and vice versa.
- As he became experienced at this task, he would learn just how much to change ***q*** for each situation. However, this relatively simple task can be easily and less expensively performed by a machine.
- The use of machines for this and similar purposes is known as ***automatic process control.***

The Unsteady State

- If a machine is to be used to control the process, it is necessary to decide in advance precisely what changes are to be made in the heat input ***q*** for every, possible situation that might occur.
- We cannot rely on the judgment of the machine as we could on that of the operator.
- Machines do not think; they simply perform a predetermined task in a predetermined manner.
- To be able to make these control decisions in advance, we must know how the tank temperature *T* changes in response to changes in *Ti* and ***q:***
- This necessitates writing the unsteady-state, or ***transient,*** energy balance for the process.

- Accumulation = input – output

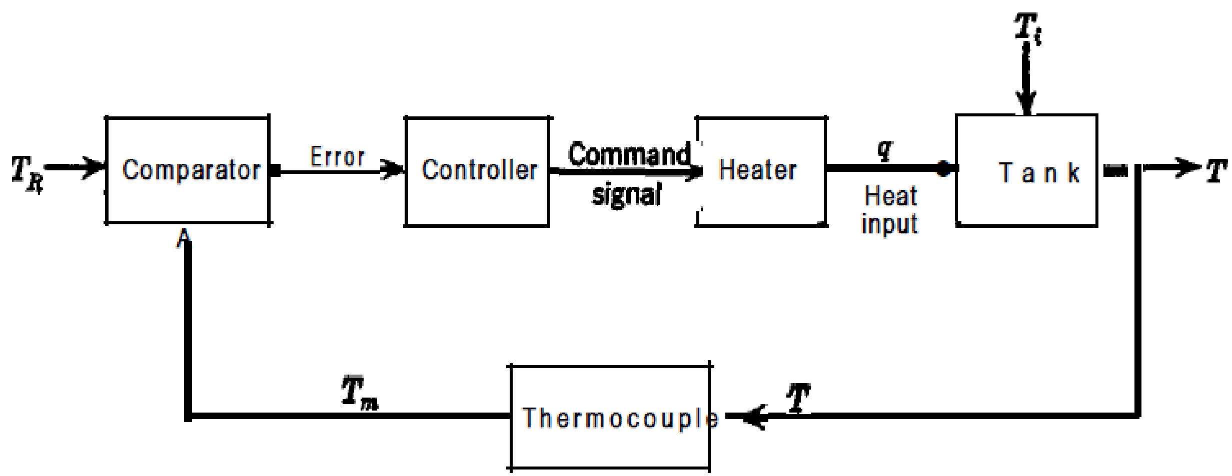
$$\rho VC \frac{dT}{dt} = wC(T_i - T) + q$$

Feedback Control

- As discussed above, the controller is to do the same job that the human operator was to do, except that the controller is told in advance exactly how to do it.
- This means that the controller will use the existing values of T and T_R to adjust the heat input according to a predetermined formula.
- Let the difference between these temperatures, $T_R - T$, ***be*** called **error**.
- Clearly, the larger this 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.

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*



- Indicates the flow of information around the control system and the function of each part of the system.
- Particularly significant is the fact that each component of the system is represented by a block.

- The major interest is in

1) the relationship between the signals entering
2) leaving the block the manner in which information flows around the system.

For example, T_R and T_m enter the comparator.

Their difference, the error, leaves the comparator and enters the controller.

Design Aspects of a process control system

The variables (flow rates, temperatures, pressures, concentrations, etc.) associated with a chemical process are divided into two groups:

1. *Input* variables, which denote the effect of the surroundings on the chemical process
2. *Output* variables, which denote the effect of the process on the surroundings

For the CSTR reactor discussed in Example

Input variables: c_{A_i}, T_i, F_i, T_{c_i}, F_c, (F)

Output variables: c_A, T, F, T_{c_o}, V

For the tank heater discussed in Example

Input variables: F_i, T_i, F_{st}, (F)

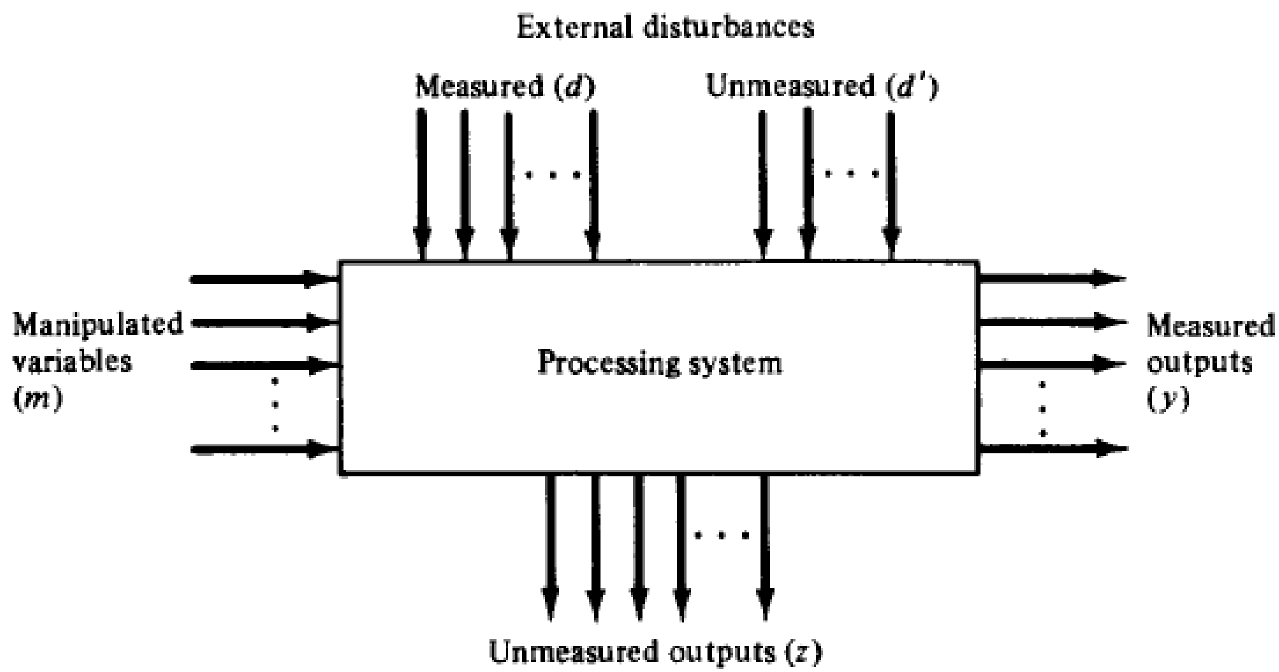
Output variables: F, V, T

The input variables can be further classified into the following categories:

1. *Manipulated* (or *adjustable*) variables, if their values can be adjusted freely by the human operator or a control mechanism
2. *Disturbances*, if their values are not the result of adjustment by an operator or a control system

The output variables are also classified into the following categories:

1. *Measured* output variables, if their values are known by directly measuring them
2. *Unmeasured* output variables, if they are not or cannot be measured directly



Design Elements of a Control System

Define control objectives

The central element in any control configuration is the process that we want to control. The first question raised by the control designer is:

Ensuring the stability of the process, or
Suppressing the influence of external disturbances, or
Optimizing the economic performance of a plant, or
A combination of the above.

It is self-evident that we would like to monitor directly the variables that represent our control objectives, and this is what is done whenever possible. Such measurements are called *primary* measurements.

It sometimes happens that our control objectives are not measurable quantities; that is, they belong to the class of unmeasured outputs. In such cases we must measure other variables which can be measured easily and reliably. Such supporting measurements are called *secondary measurements*.

Then we develop mathematical relationships between the unmeasured outputs and the secondary measurements; that is,

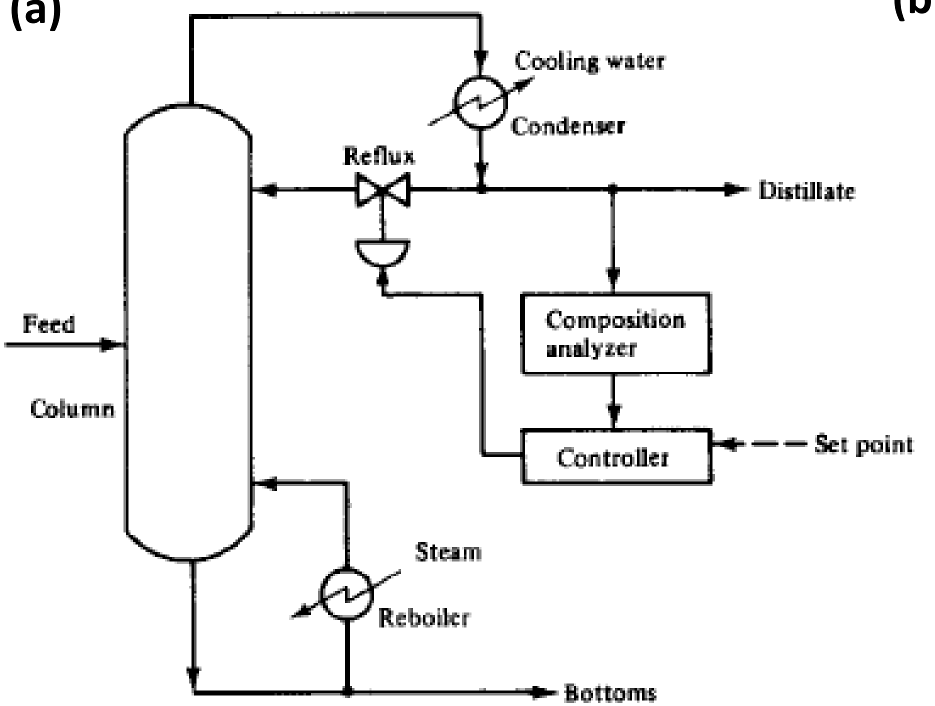
$$\text{unmeasured output} = f(\text{secondary measurements})$$

Feed forward control

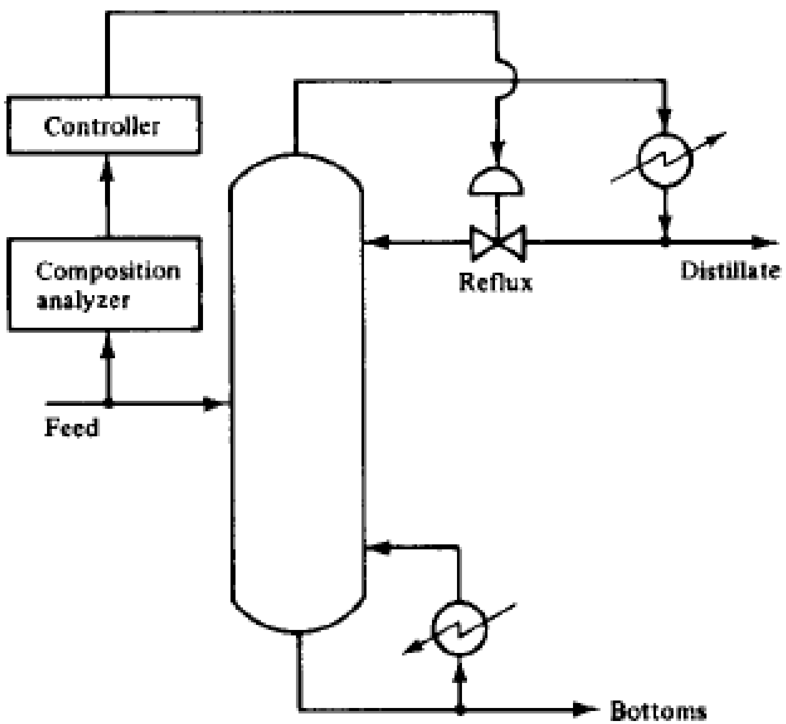
The third class of measurements that we can make to monitor the behavior of a chemical process includes direct measurement of the external disturbances. Measuring the disturbances before they enter the process can be highly advantageous because it allows us to know *a priori* what the behavior of the chemical process will be and thus take remedial control action to alleviate any undesired consequences. Feedforward control uses direct measurements of the disturbances (see Figure 1.4).

Figure 2.2 Three different systems for the distillate composition control of a simple distillation column: (a) feedback; (b) feedforward; (c) inferential.

(a)



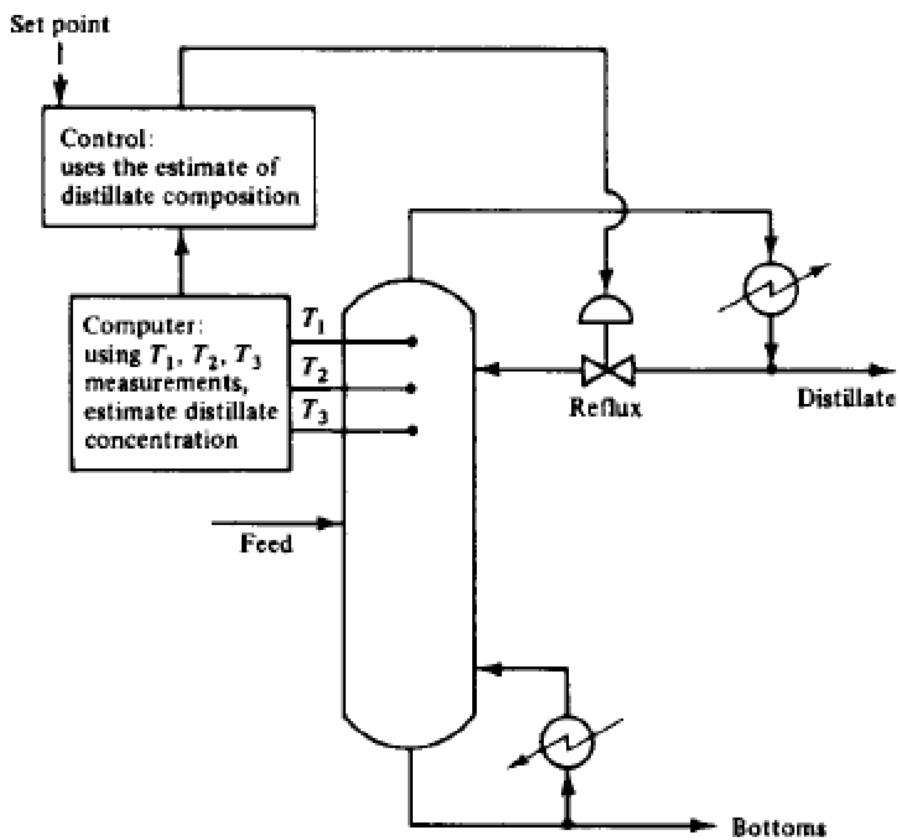
(b)



Temperature measurement (Secondary measurement)

Measuring the composition (a), (b) either very costly or of low reliability for an Industrial environment. In such cases we can measure the temperature of the liquid at various trays along the length of the column quite reliable using simple thermocouple.

(C)



Manipulated variable

Usually in a process we have a number of available input variables which can be adjusted freely. Which ones we select to use as manipulated variables is a crucial question, as the choice will affect the quality of the control actions we take.

Control configuration

A control configuration is the information structure that is used to connect the available measurements to the available manipulated variables.

It is clear from the previous examples that normally we will have many different control configurations for a given chemical process,

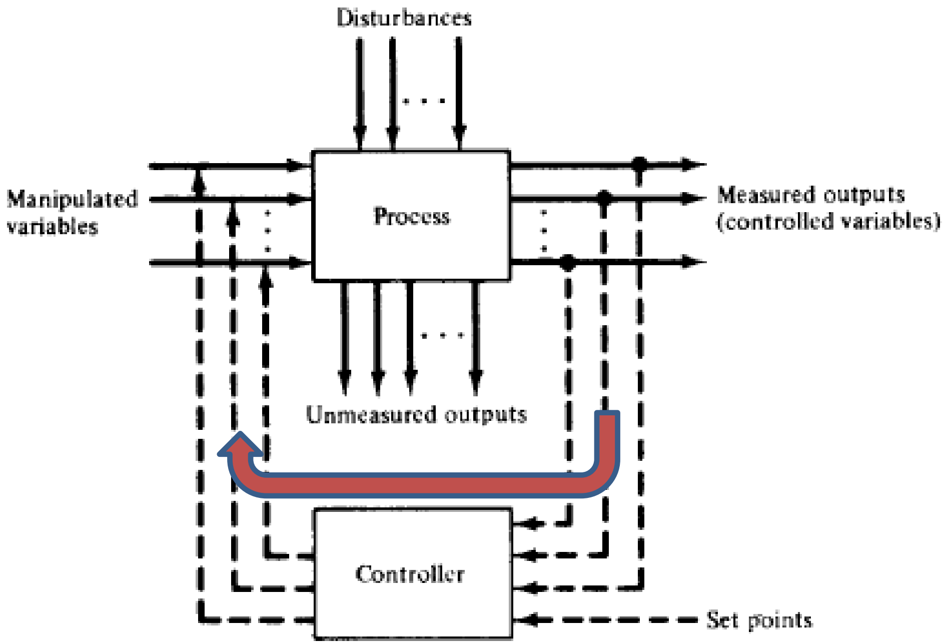
Depending on how many controlled outputs and manipulated inputs we have in a chemical process, we can distinguish the control configurations as either *single-input, single-output* (SISO) or *multiple-input, multiple-output* (MIMO) control systems.

For example, for the tank heater system:

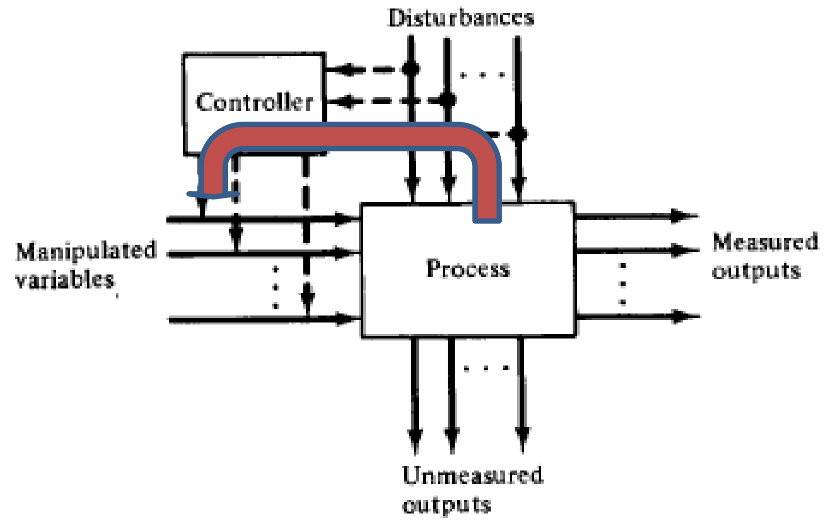
(a) If the control objective (controlled output) is to keep the liquid level at a desired value by manipulating the effluent flow rate, we have a SISO system.

(b) On the contrary, if our control objectives are (more than one) to keep the level and the temperature of the liquid at desired values, by manipulating (more than one) the steam flow rate and the effluent flow rate, we have a MIMO system.

Three general type of control configuration

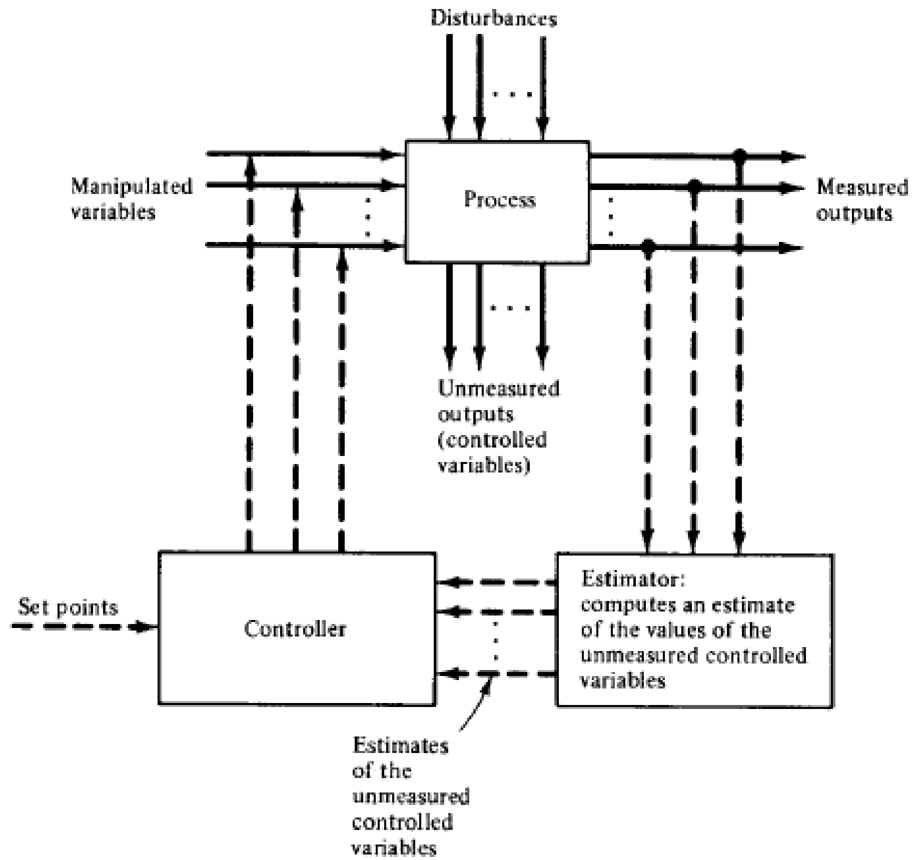


Feedback control



Feedforward control

General structure of inferential control configurations.



Inferential control configuration: uses secondary measurements (because the controlled variables cannot be measured) to adjust the values of the manipulated variables (Figure 2.4). The objective here is to keep the (unmeasured) controlled variables at desired levels.

Hardware for a process control system

Hardware elements for the control configuration can divided in following:

1. **The chemical process**: Equipment, material with physical or chemical change
2. **The measuring instruments or sensors**: Instruments that used to measure the disturbances, the controlled output variables or secondary output variable

For example

Thermocouples or resistance thermometers, for measuring the temperature

Venturi meters, for measuring the flow rate

Gas chromatographs, for measuring the composition of a stream

- Measuring device should transmit the information.
- Thus transmission is a very crucial factor in selecting the measuring devices.
- Good measurements are required for good control

Transducers

Transducers are used to convert measured variable into some physical quantities (such as electric voltage, current, pneumatic signal) which can be transmitted easily.

Example: convert pressure signal to an electric current

Transmission line

- Used to carry the measured electric signal from measuring device to the controller.
- Many times measured signal are very weak we can use amplifiers.

  For e.g. output of a thermocouple is order of millivolts can amplified to the level of few volts

The controller:

- The hardware element that has“ intelligent”
- It receives the information from the measuring devices and decides what action should be taken
- The increasing use of digital computers as controllers, the available machine intelligence has expanded tremendously.
- Very complicated control law can be implemented.

The Final control element

This is a hardware that implements in real life the decision taken by the controllers.

For example if the controller decide at the flow rate of the outlet is stream should be increased or decrease in order to keep the liquid level in a tank.

it is the valve that will implement this decision opening or closing by the commanded amount.

the control valve is most frequently encountered final control element for example other type of final control element for chemical process

Relay switches providing on off control

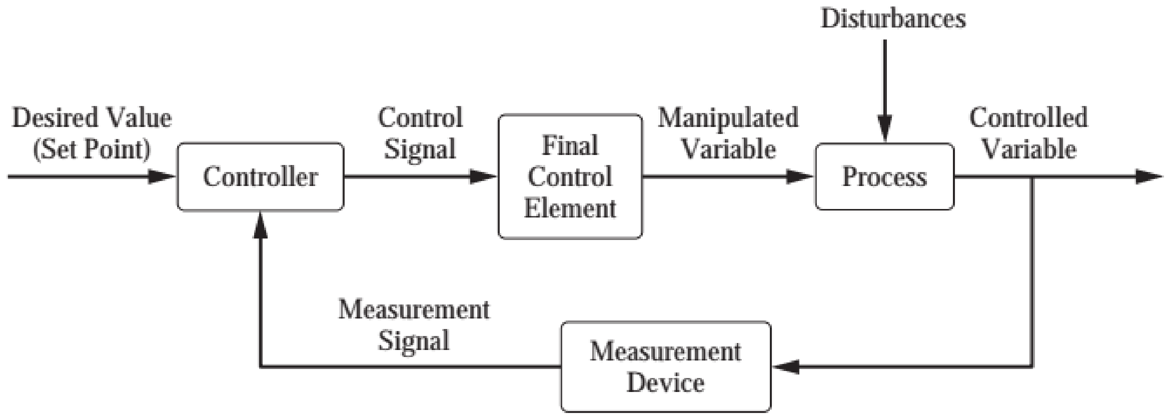
Variable speed compressors

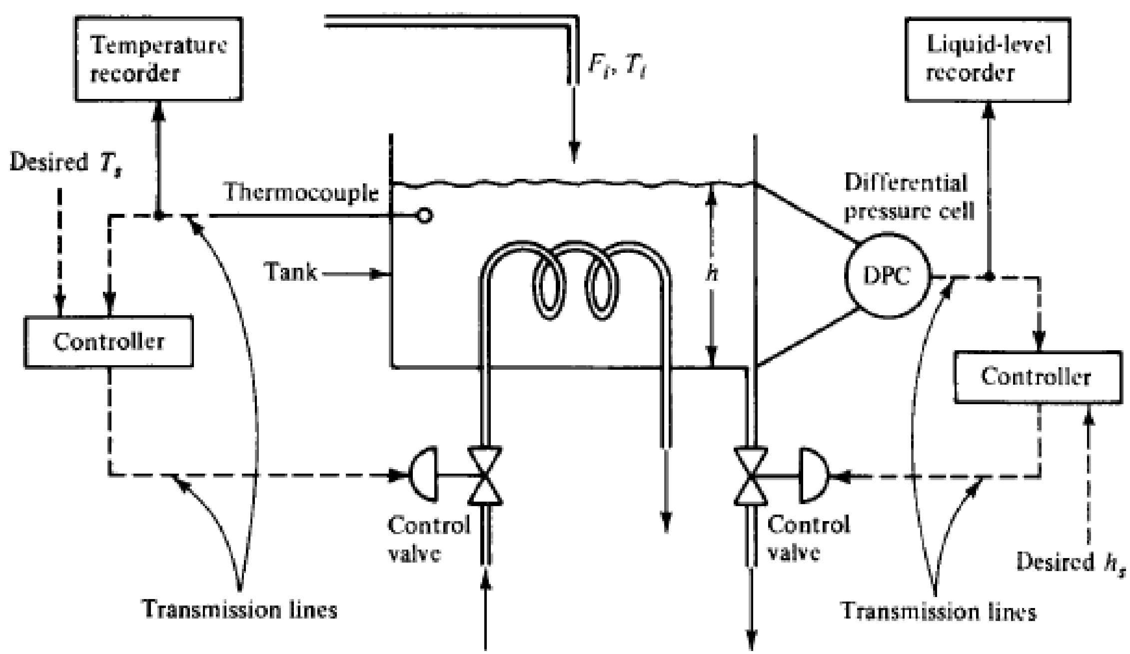
Variable speed pumps

Recording elements:

- **T**hese are used to provide a visual demonstration of how a chemical process behave.
- Usually the variable recorded are variables that are directly measured as a part of the control system.
- Various type of recorders (temperature, pressure, flow rate, composition etc.) can be seen in the control room of a chemical plant.
- The recent introduction of the digital computer in the process control has also expanded the recording opportunities through videos display units (VDUs).

hardware elements for the feedback control of a stirred tank heater





Use of digital computer in process control

- The fundamental Revolution introduced by the digital computer in the practice of process control is the Virtually unlimited intelligence that can be exhibited by such units.

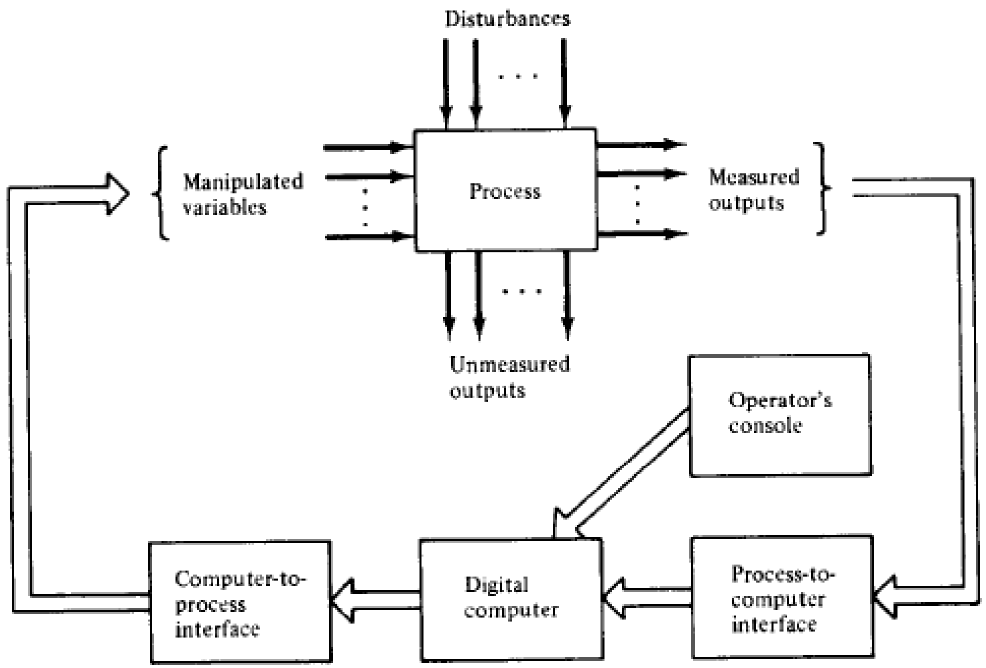
- This phenomenon employees that the control law that can be used are much more complex and sophisticated.

- Furthermore, the digital computer with its easily programmed inherent Intelligence “can learn” as it receive measurements from the process and it can change the control that is implementing during the actual operation of the plant.

- We will discuss some application characteristics of the diverse uses of digital computers

Direct digital control (DDC)

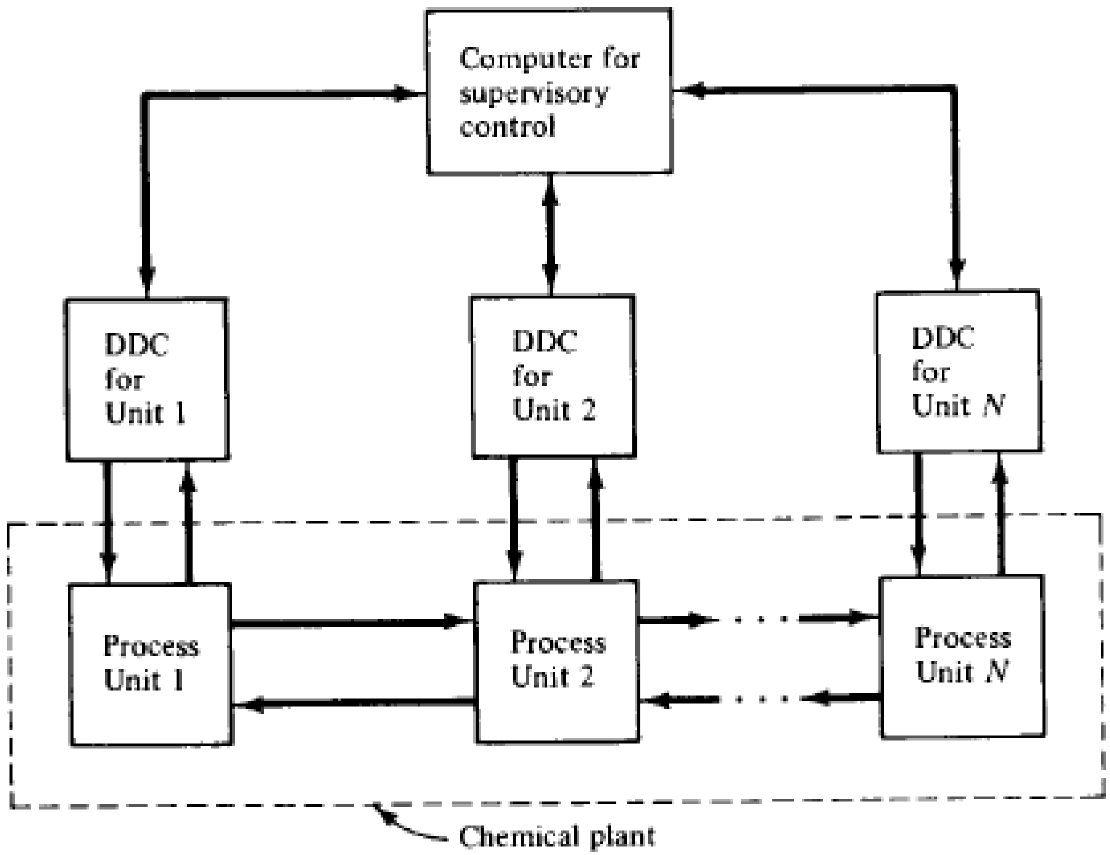
- In such application the computer received directly the measurements from the process.
- Based on the controller which is already programmed and reside in the memory calculate the value of the manipulated variables.
- These decisions are now implemented directly on the process by the computer through the proper adjustment of the final control element.
- This direct implementation of the control decision give rise to the name direct digital control



Supervisory computer control

- One of the incentive for process control is the optimisation of the plants economic performance.
- Many times the human operator does not or cannot find the best operating policy for a plant which will minimise operating cost.
- This deficiency is due to enormous complexity of the typical chemical plant .
- In such case we can use speed and the program intelligence of digital computer to analyse the situation and suggest the best policy.
- The computer coordinates the activities of the basic DDC loop.

Structure of supervisory computer control



Scheduling computer control

- Computer can be used to schedule the operation of a plant
- For example the condition in the market change with time requiring the management of the chemical plant to change its operational schedule by cutting production to avoid overstocking increase production to meet the demand changing over a new production line and so on.
- These decisions can be made rationally with the aid of a digital computer which in turn will communicate these decisions to the supervisory computer control.
- Finally the supervisory controller will implement this decision on the chemical plant through DDCs