Chemical Process Dynamics and Control

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Chapter Objectives

End of this chapter, you should be able to:

1. Describe the role of process dynamics and control in industry
2. Classify process variables
3. Describe various control strategies
4. Describe design elements of a control system
5. Describe control aspects of complete chemical plant
6. Identify hardware elements of process control system

Introduction to process control

1. Control what is it?

   Control is defined as a set of organized actions directed towards achieving or maintaining a specific goal (dynamic commands, regulation and co-ordination of the system), as an example the natural control (nervous system and muscles) in which a series of organized actions is taken to maintain the specific goal of human safety.

2. Examples
3. Control how old is it?

The role of process dynamics and control

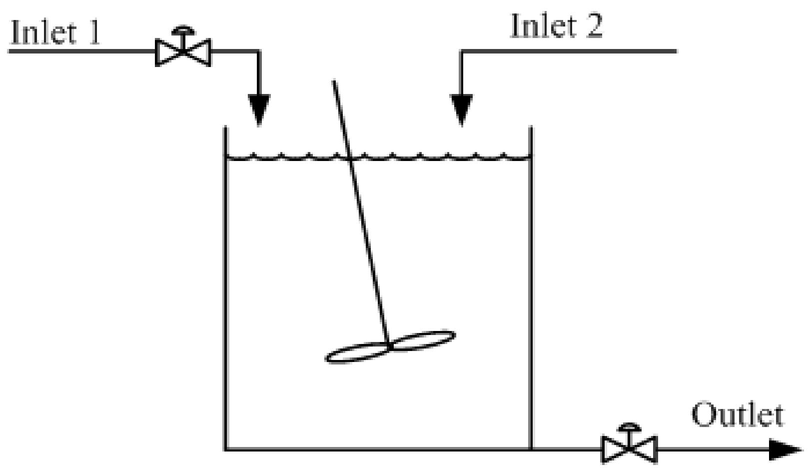
Some of the roles of process dynamics and control

1. Understanding dynamic behavior of processes (open-loop)
2. Designing control system that address specific control problems? (Closed-loop)
3. Tuning of controllers
4. Stability analysis of controlled processes

The role of process dynamics and control

✓ Understanding dynamic behavior of processes

Gravity flow mixer

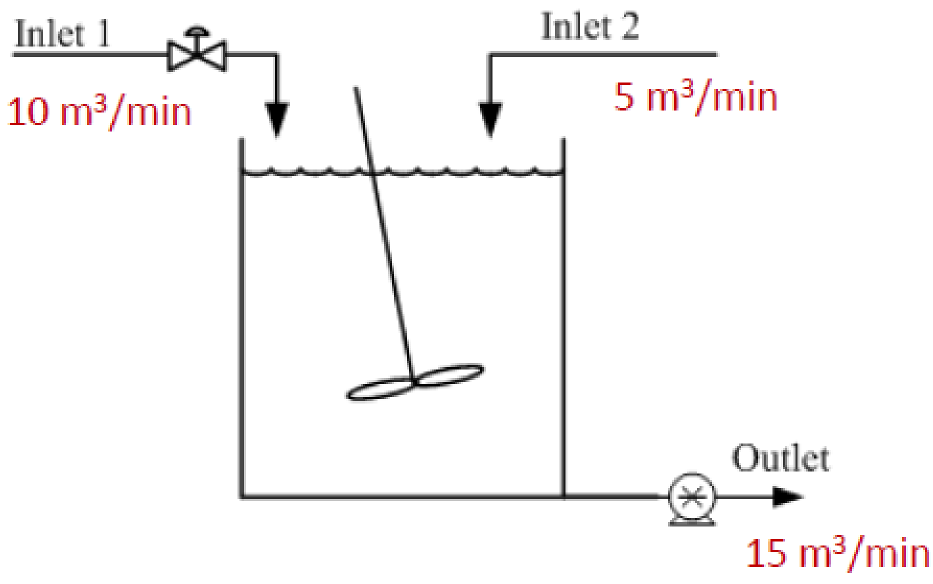


- What happens to the liquid level with time (dynamically) if inlet 2 increases ?
- How can I maintain the liquid level at the desired value?

The role of process dynamics and control

Constant outlet mixer

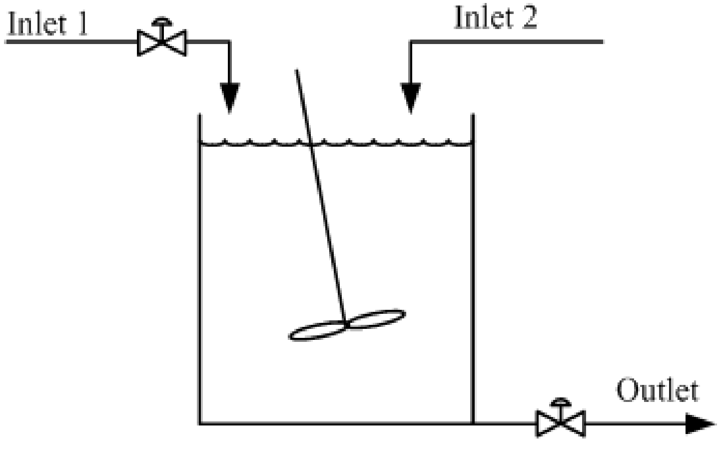
What is the difference in the dynamic behavior of the system below to the previous one?



The role of process dynamics and control

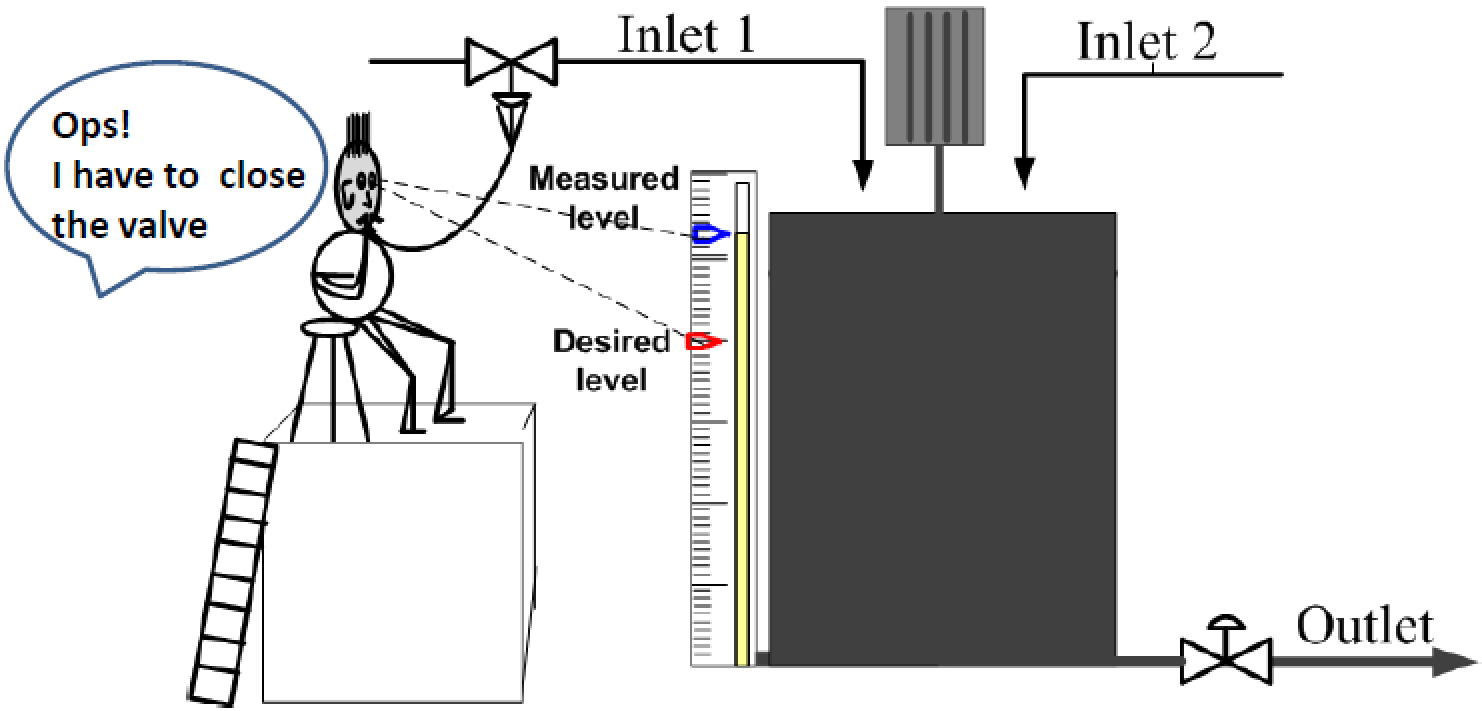
Two types of control problems

- How to maintain the liquid level in the tank at a desired value irrespective of variations in flow rate of Inlet 2 (disturbance)? (Regulator problem)
- How to adjust the liquid level in the tank to a new desired value (set point) in an optimal way (quickly and smoothly)? (Servo problem)



Designing the control system

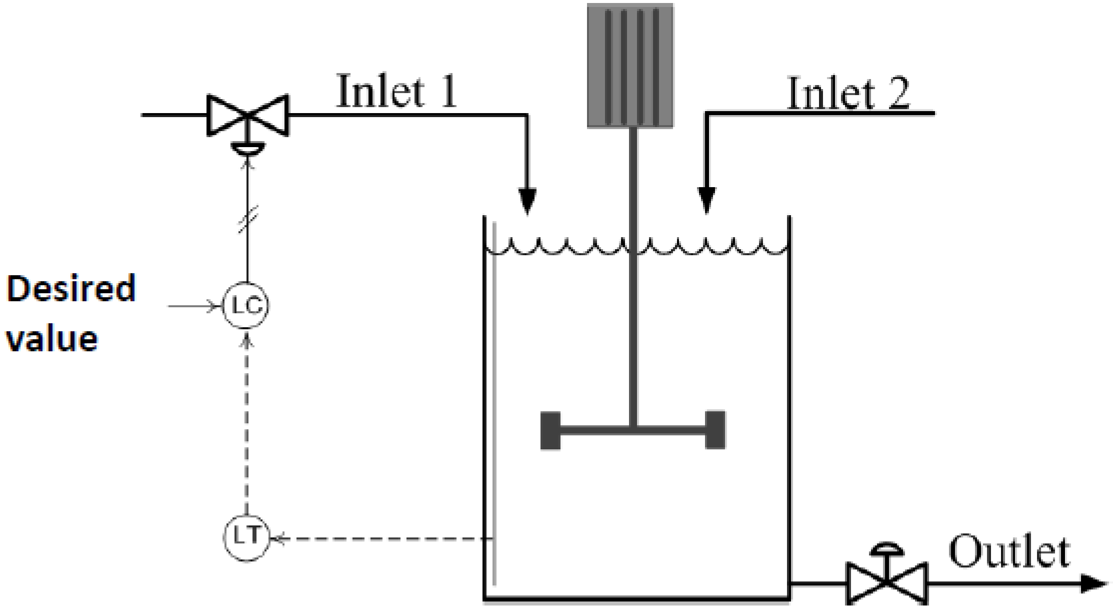
- ✓ What if I assign a human operator?



The operator compares the measured value with the desired value (set point) and adjusts the control valve.

Designing the control system

✓ Automatic process control



The controller compares the measured value with the desired value and adjusts the control valve.

Designing the control system

- The merits of automatic control over manual control are

✓ Freedom of the system from human limitations

Efficiency of the human operator varies among individuals and from time to time depending upon factors such as; health and environmental conditions together with the mode, morale and psychology of the operator

✓ Process efficiency

Can be held closely to their optimum conditions.

Designing the control system

- ✓ Productively Gains

  Automation considerably improves labor productivity hence large no of skilled labors are saved and transferred to other jobs

  This can lower production cost

- ✓ Improvement of Equipment utilization factor

  Control ensures a better utilization of plant equipment, reduces shut – down time and permits significant improvements in operation and design of process equipment

Process Variables

To mathematically express the dynamic behavior of a process it is necessary to identify the three important types of variables

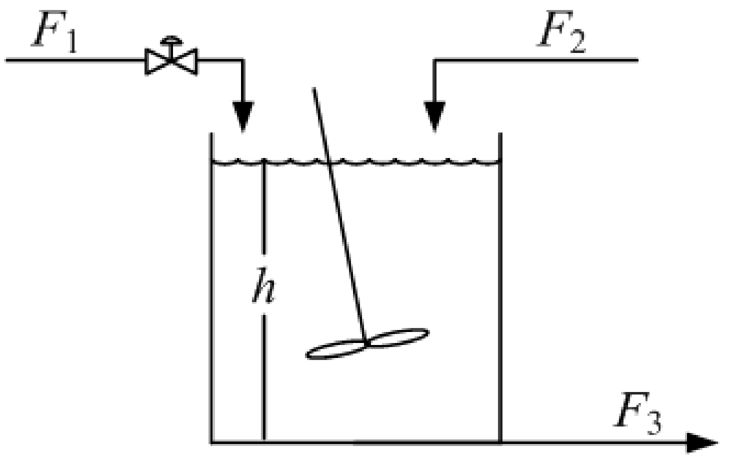
1. Controlled variables -these are the variables which quantify the performance or quality of the final product, which are also called output variables

2. Manipulated variables -these input variables are adjusted dynamically to keep the controlled variables at their set-points

3. Disturbance variables -these are also called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points

Process Variables

Classify the process variables

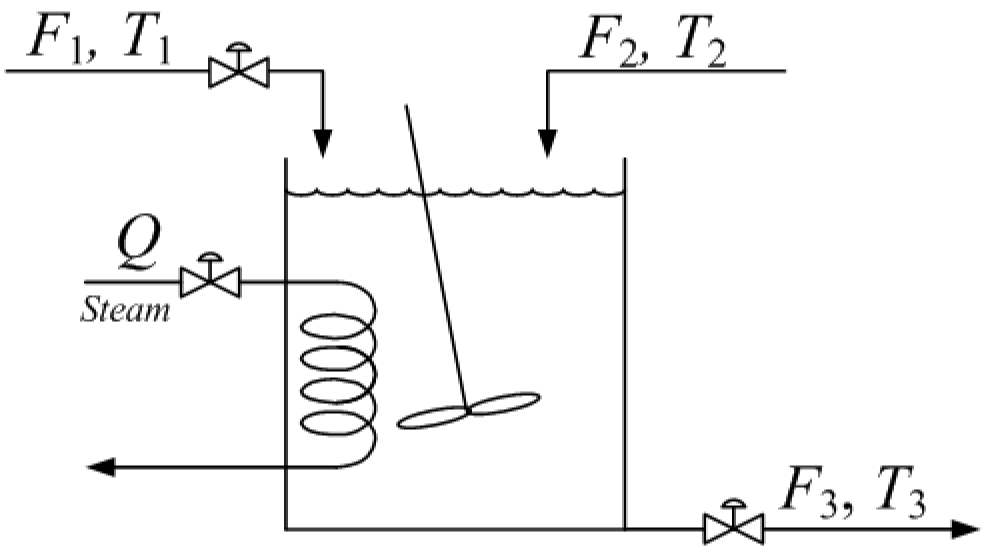


Process variables

CV: h, (F3)
MV:F1
DV: F2

Process Variables

Classify the process variables in the stirred tank heater



Process variables

CV: h, T3
MV:F1, F3, Q
DV: F2 , T1 ,T2

Control strategies

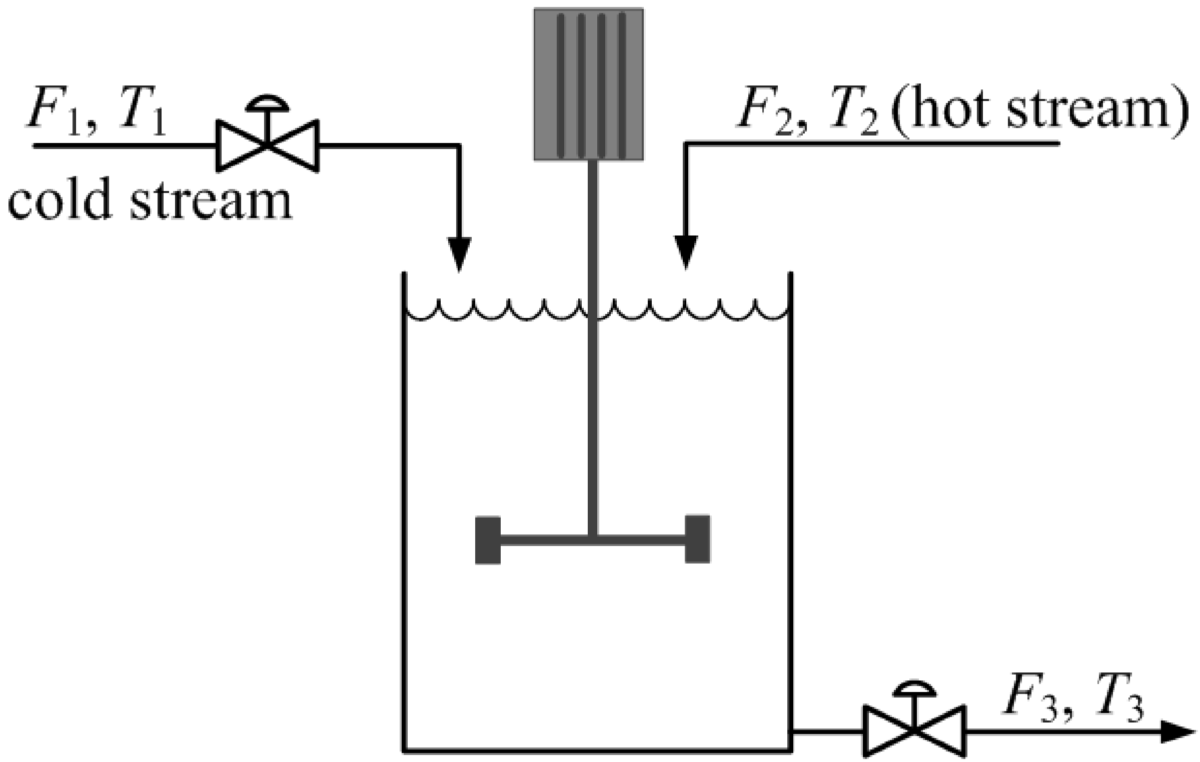
The two most common control strategies are:

- Feedback control strategy :-Control action is based on the measurement of controlled variable.

- Feed forward control strategy :-Control action is based on the measurement of disturbance.

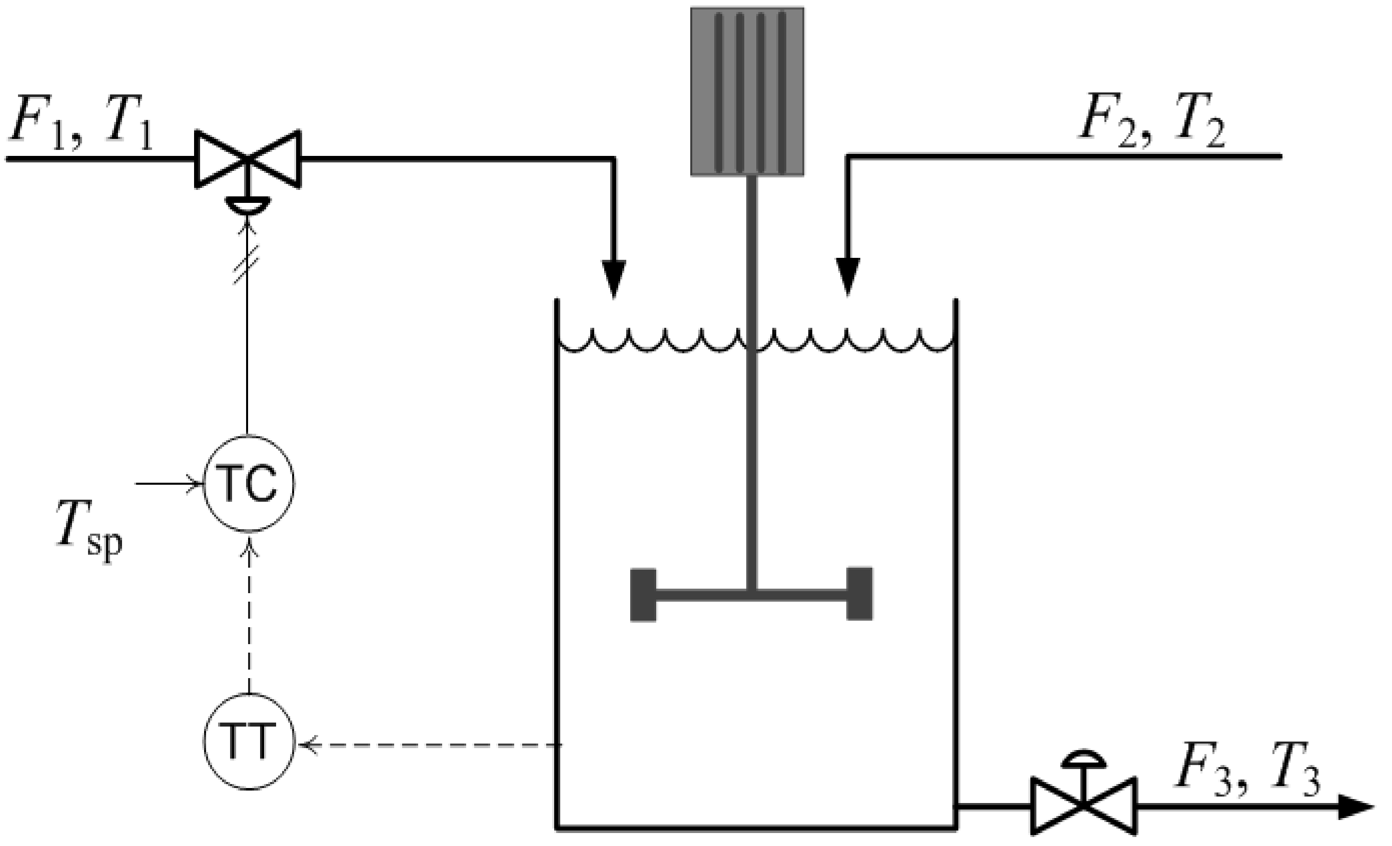
Control strategies

Propose a control strategy to maintain the outlet temperature at a desired value. The variation in flow rate of the hot stream is negligible . The variation in the hot stream temperature is more considerable than the cold stream temperature.



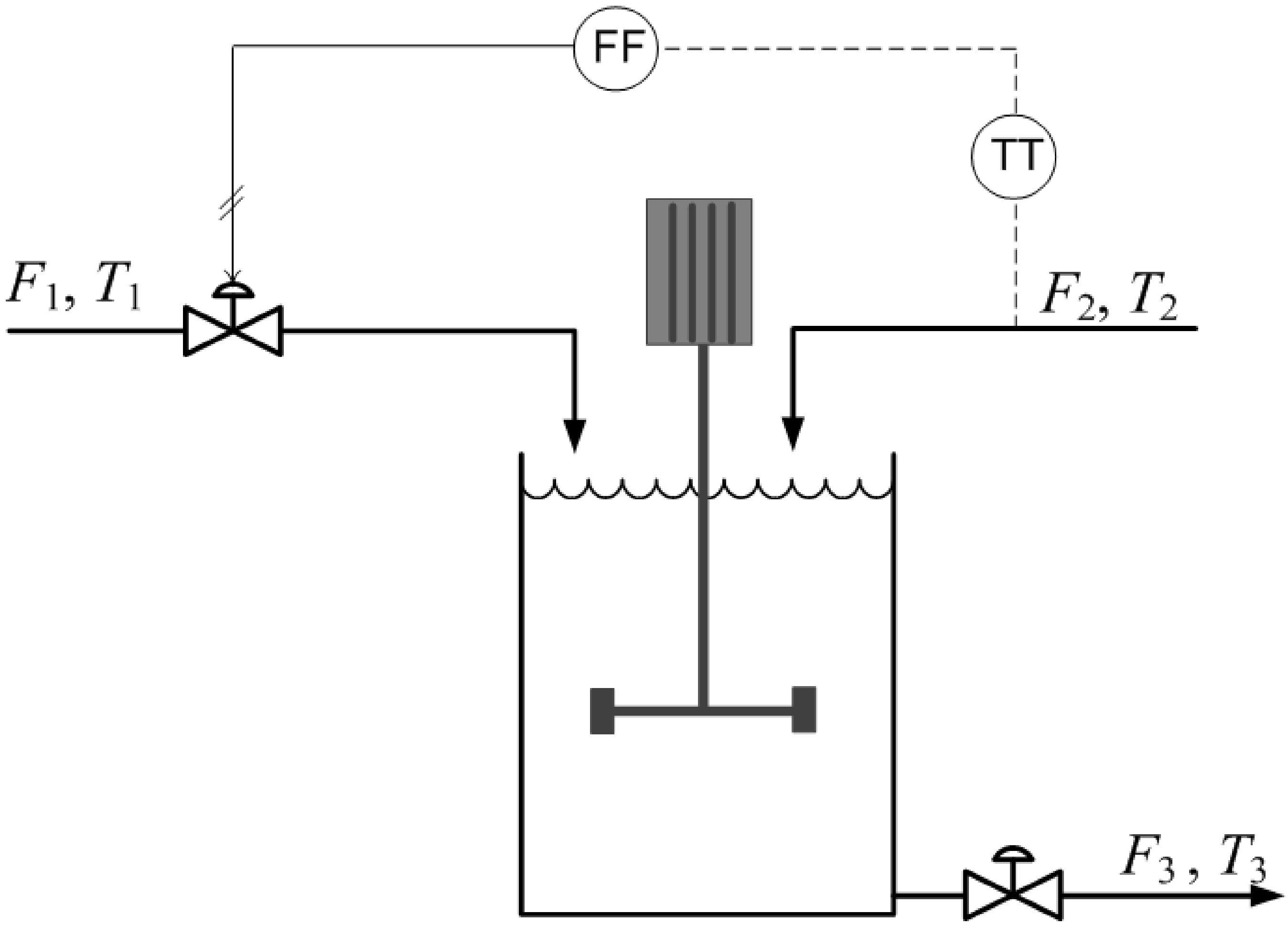
Control strategies

Feedback control strategy



Control strategies

Feedforward control strategy :- Control decision is based on measurement of disturbance



Control strategies

Advantages and disadvantages of feedback and feedforward control strategies

Feedback

Advantage

- Design of controller does not depend on model accuracy

Disadvantage

- No corrective action is taken until after the disturbance upsets the process.
- May cause oscillatory responses or even instability.

Feed forward

Disadvantage

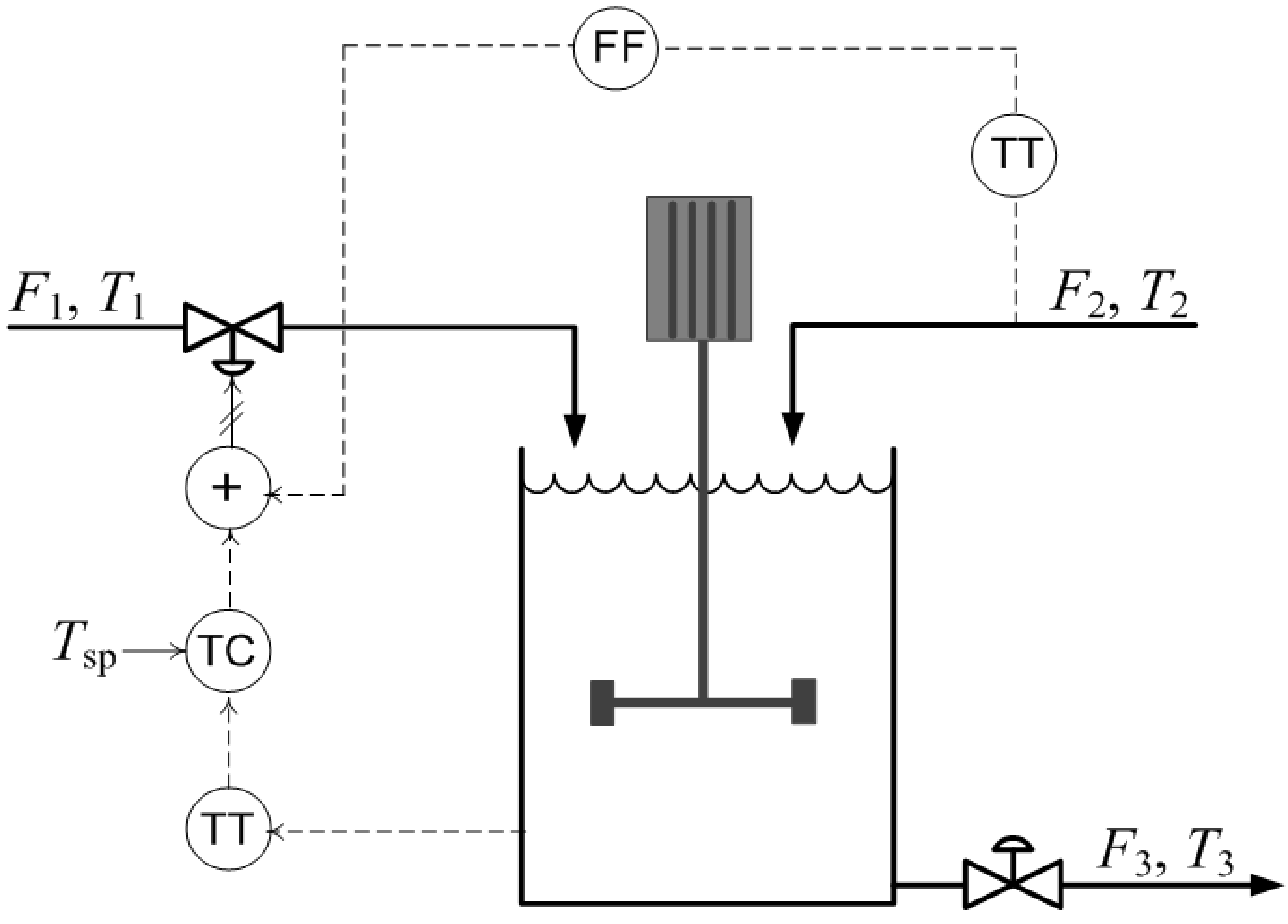
- Design of controller highly depends on model accuracy

Advantage

- No corrective action is taken before disturbance upsets the process.
- Will not cause oscillatory responses and instability

Control strategies

Feedback-Feedforward control strategy



Design Elements of a Control System

- ✓ Design elements of a control system

1. Defining the control objective
2. Identifying the relevant process variables and classifying them
   - Select measurements
   - Select manipulated variable
3. Selecting the appropriate control configuration
4. Designing the controller
   - Identify the controller type (Control law)
   - Determine the setting of the controller parameters (Tuning)

Design Elements of a Control System

1. Defining control objective

- ✓ To design a control system that will satisfy the control need of a chemical process, the control objective should be clearly identified and defined quantitatively
- ✓ The control objective may be related to
  - Ensuring stability
  - Suppressing the influence of external disturbances
  - Optimizing the economic performance of a plant
  - A combination of the above

Example:-Control objectives

“To stabilize the reaction temperature at 800C “

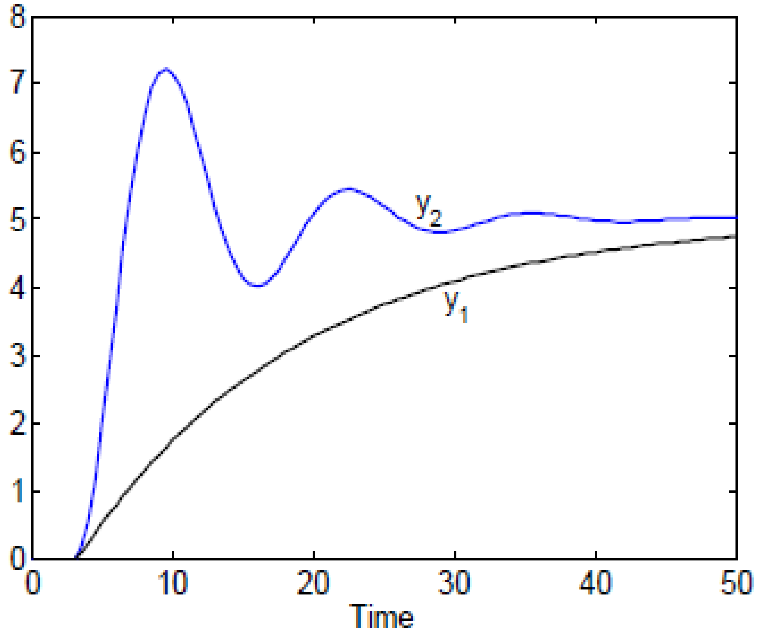
“To maintain the liquid level in the mixer at 3±0.2 m”

“ To maximize the profit of a batch reactor after a period of the reaction time (2 hr)“

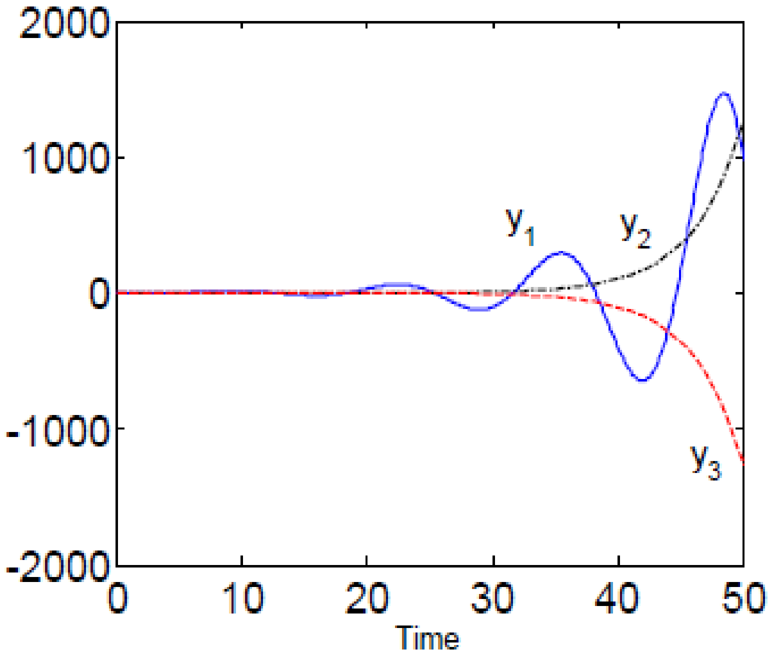
Design Elements of a Control System

✓ Stable system

A system is said to be stable if bound change in input causes bounded change in output, otherwise it is unstable



Stable responses



Unstable responses

Design Elements of a Control System

✓ Identifying and classifying relevant process variables:

- Identifying the process variables that are directly and indirectly related to the control objective is essential for designing the control system

- The variables should then be classified into controlled, manipulated and disturbance variables

- The variables that can be measured will affect the control strategy to be used therefore it is necessary to check if the CVs and DVs can be directly measured

Design Elements of a Control System

- ✓ Designing the controller

- ✓ Selecting the control law that will satisfy the control objective

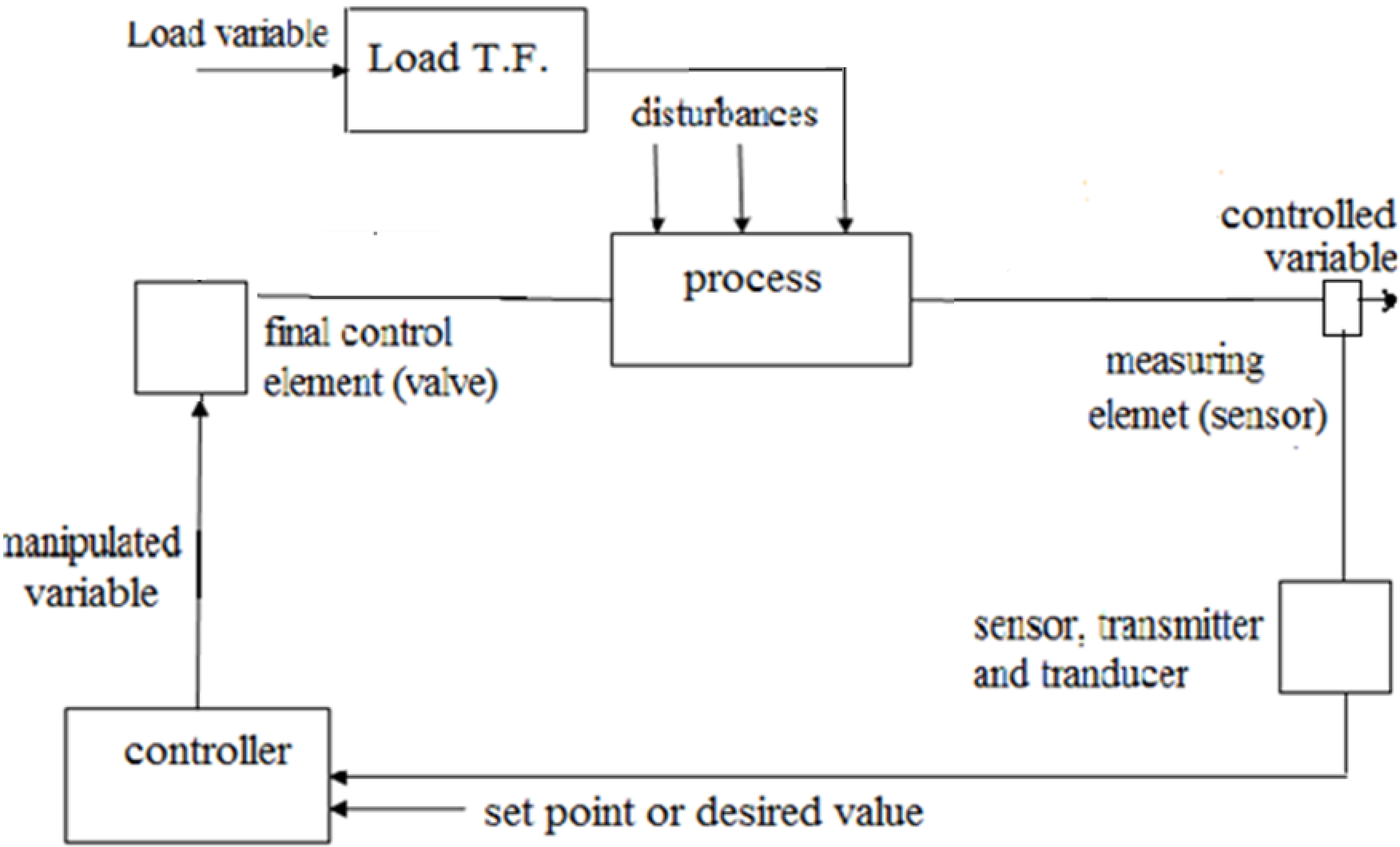
  - Example: Proportional-Integral (PI)/ (To be studied in latter chapters)

- ✓ Setting the parameters of the controller (Tuning)
  Generally controllers have parameters to be adjusted

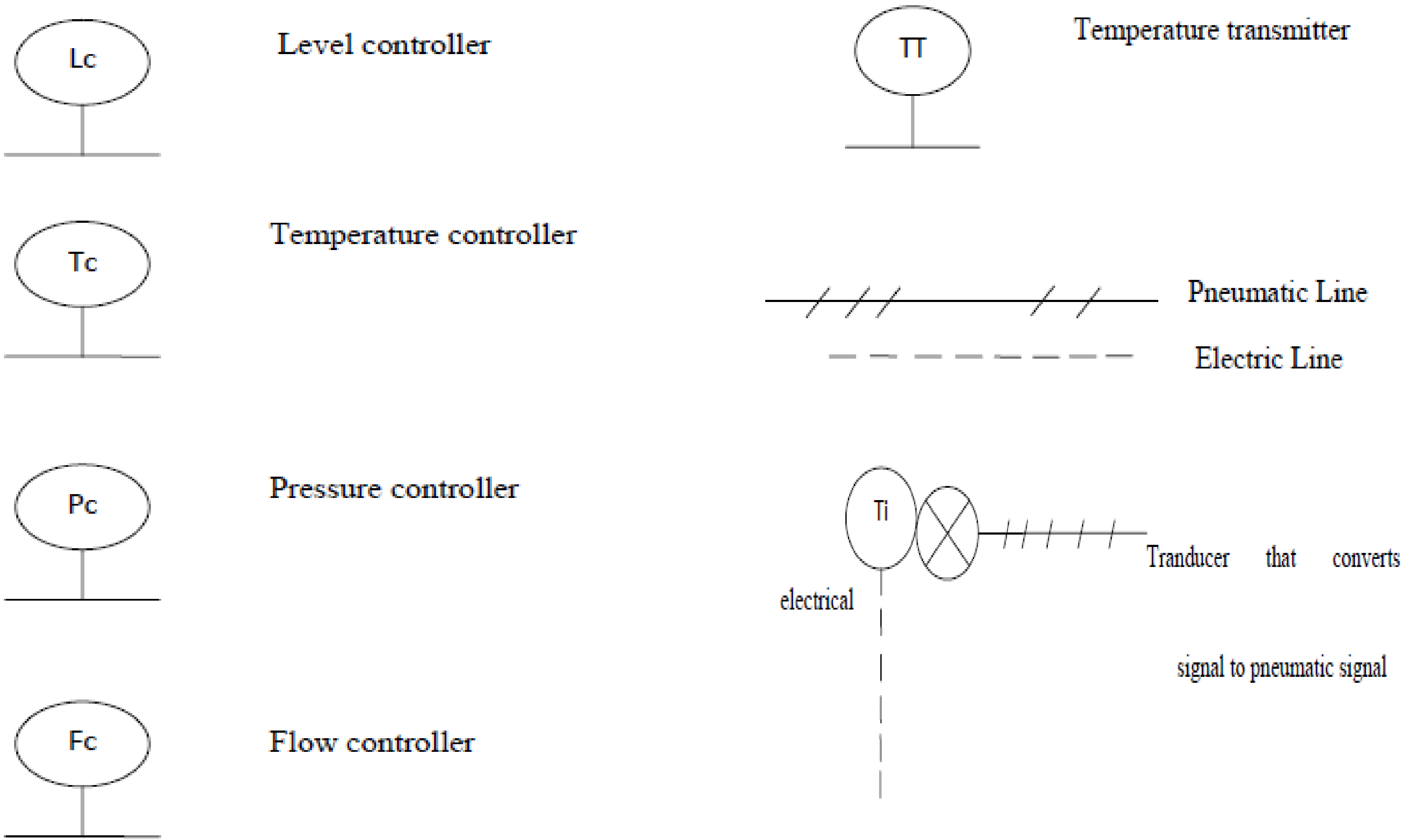
  - Example: a PID controller has three parameters that can be adjusted

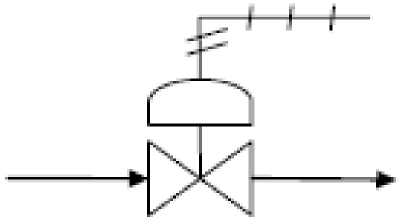
- ✓ The values of the tuning parameters play a very critical role in the performance of the controller

Design Elements of a Control System

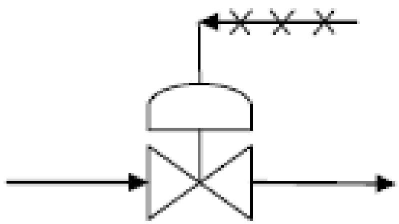


Physical Diagram Symbols used

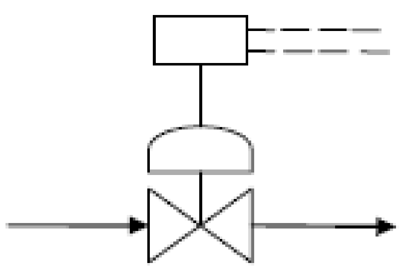




Control valve with pneumatic signal

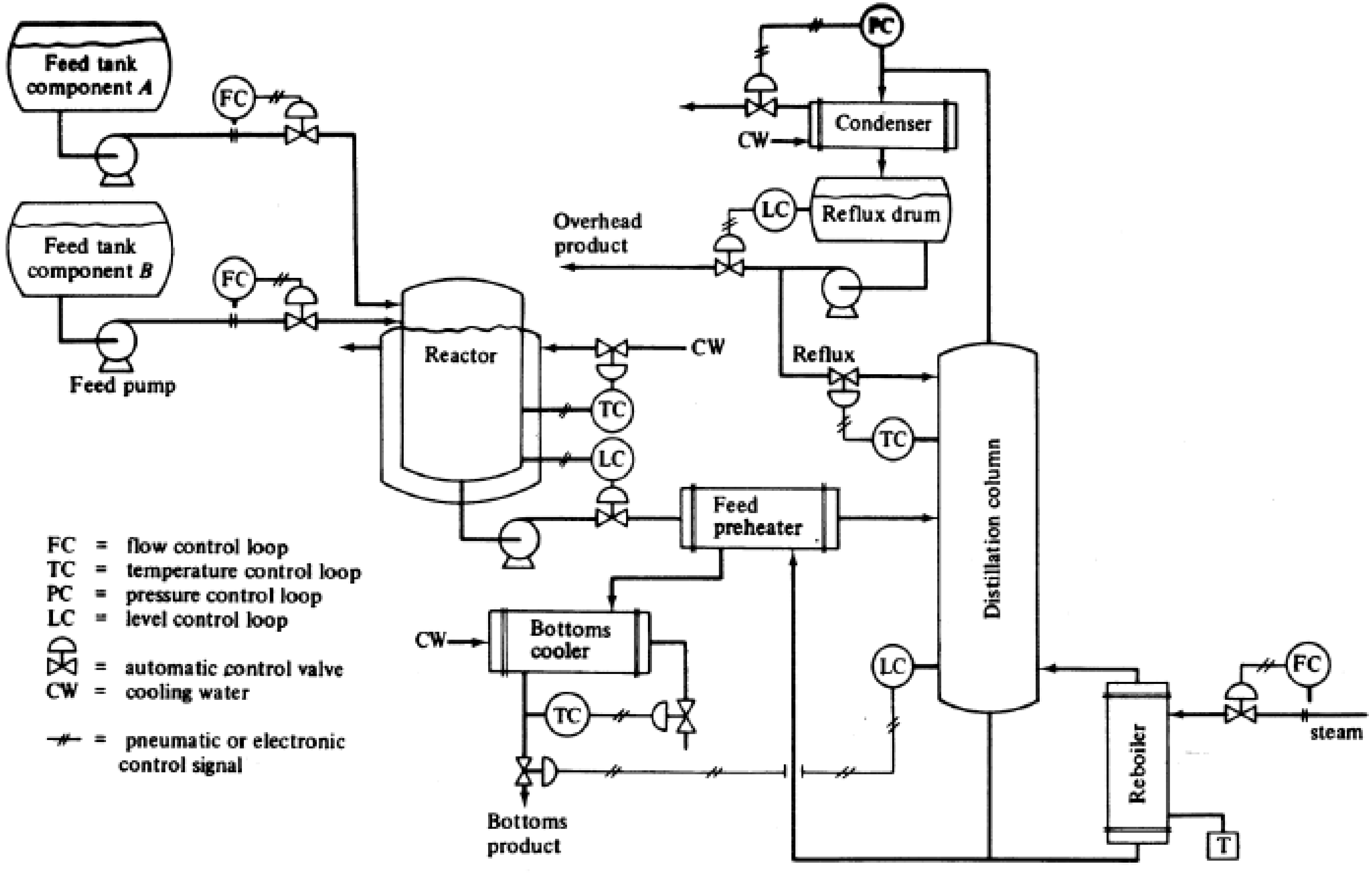


Control valve with hydraulic signal



Control valve with electrical signal

Control Aspects of a Complete Chemical Plant



Hardware Elements of A Control System

- ✓ The main hardware elements of a control system are

1. The unit operations
2. The measuring instruments or sensors
3. Transmitters
4. Controller
5. Transducers
6. Final control element

Hardware Elements of A Control System

1. The Unit Operations :-They represent the physical equipment, together with the physical or chemical processes that occur there.

2. Measuring Instrument or Sensor :-They are used to measure disturbances, controlled variables or secondary variables.

Variable	Sensors
Temperature	Thermocouples, resistance thermometers
Flow meters	Orifice, turbine flow meters
Liquid level	Differential pressure sensors
Pressure	Capacitance measurement, piezoelectric
composition	Chromatographic, mass spectrometers

Hardware Elements of A Control System

- Sensors

Pressure sensor

Temperature sensors (Thermocouples)

Liquid level sensors

Turbine flow sensors

Flow sensors

Orifice

Hardware Elements of A Control System

3. Transmitters

   Are used to convert the out put from the sensor to a standard signal, mostly 4-20 mA electrical signal or 0.2 to 1 bar (3-15 psig) pneumatic signal and send it to the controller.



Hardware Elements of A Control System

4. Transducers

They are used to convert one form of signal to another

Example :-

I/P current to pressure converter

A "current to pressure" converter (I/P) converts an analog signal (4 to 20 mA) to a proportional linear pneumatic output (3 to 15 psig).

Hardware Elements of A Control System

5. Controller

   Is the hardware element that receives signal from the measuring device and decides what control action should be taken.

Field mounted controllers

DCS room

Hardware Elements of A Control System

6. Final Control Element

   The hardware element that receives signal from the controller and manipulates the process to be controlled. The single most common type of final control element in process industries is the control valve (pneumatic control valve)