KG32903 PROCESS CONTROL AND INSTRUMENTATION

CHAPTER

1

Introduction to Process Control

(Lecture week 1&2)

UNIVERSITI MALAYSIA SABAH

Prepared by Dr. Suhadat

CHAPTER OVERVIEW & LEARNING OUTCOMES

- **1.1 Basic concept of control system**
- **1.2 Control objective and application**
- **1.3 Process control problem and variables**
- **1.4 Typical control loop and strategy**

At the end of this chapter, you should be able to:

1. Understand the role of process dynamics and control in industry
2. Understand the concept of a control system
3. Identify the important of process control objective and it's variables
4. Identify control loop of feedback and feedforward method
5. Relate the control objective and strategy for a control loop decision

Overview of a typical chemical plant and control system

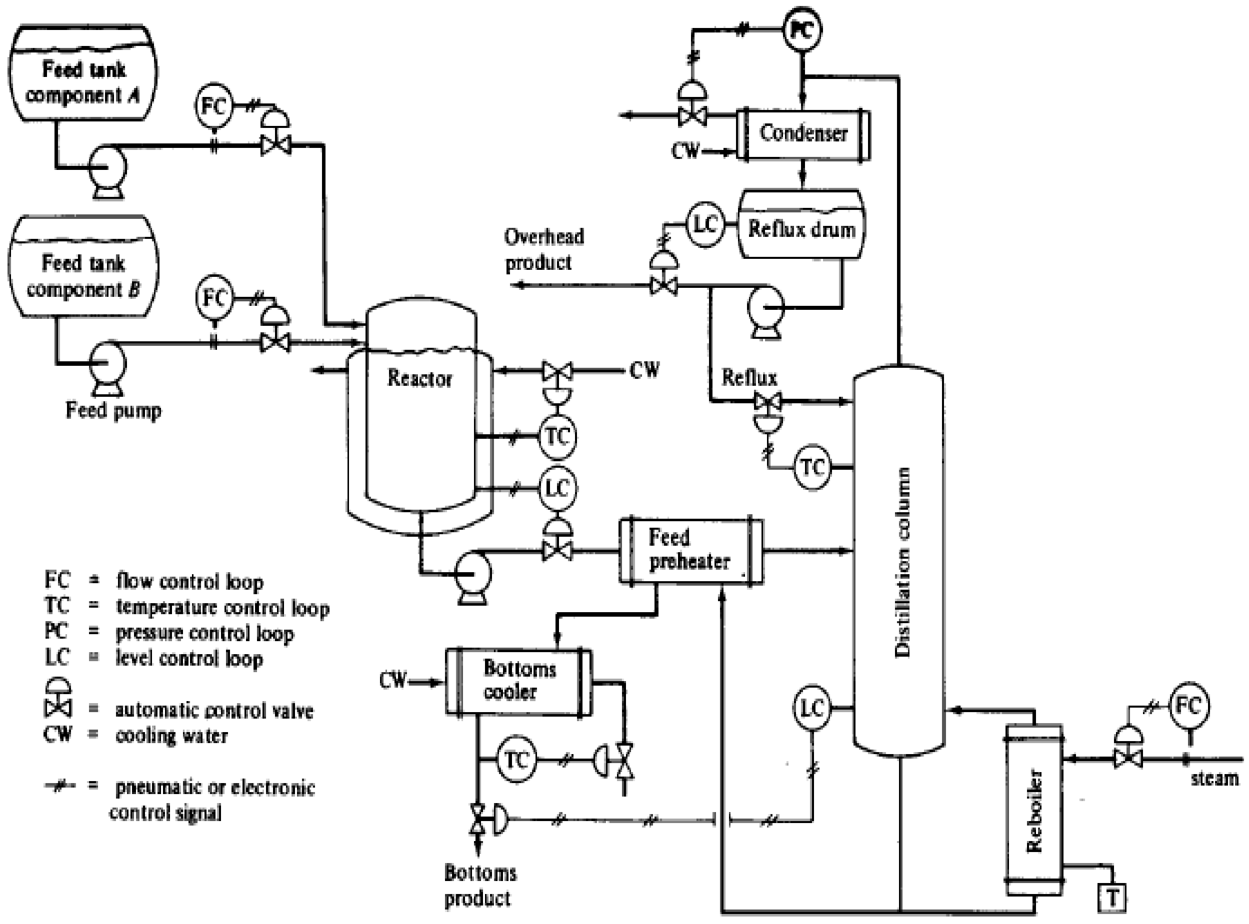
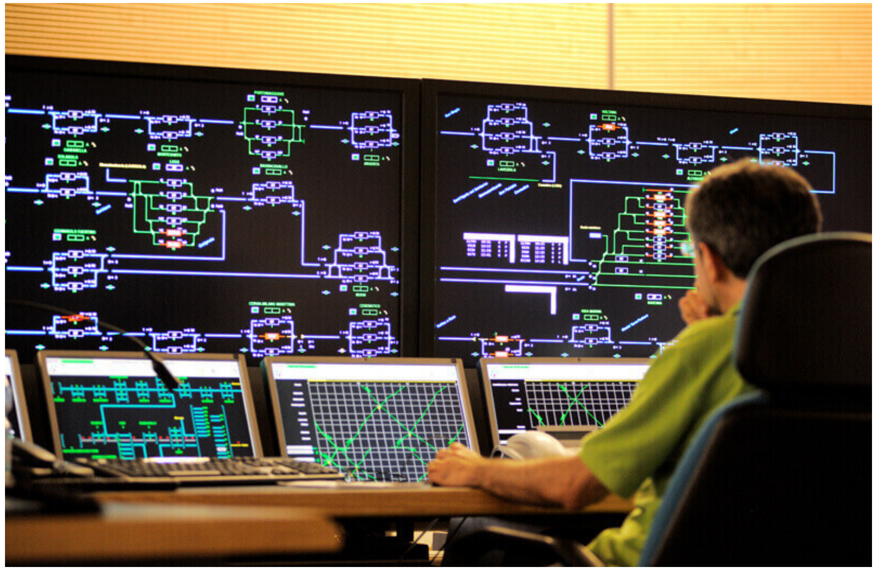


FIGURE 1.5
Typical chemical plant and control system.

- Any chemical plant consist of various process units which are inter connected with one another in systematic manner
- Main objective of any plant is to convert certain raw materials into desired product using available sources of energy
- Other objective- safety, product specification, environmental regulations, operation constraints, economics
- These all parameter are control by arrangement of various equipment like measuring devices, valves and controller

Career in Process Control and Instrumentation

- Control and instrumentation engineers ensure that industrial equipment and machinery work safely and efficiently. They may work in an office, a laboratory, on a factory floor or all three.
- Can become a technical “Top Gun”
- Provides professional mobility. There is a shortage of experienced process control engineers
- Is a well paid technical profession for chemical engineers



1.1 Basic concept of process control system

- Foundation of process control is *process understanding.*
- What is a **process**?

  "The conversion of feed materials to useful products using chemical and physical operations"

- Common processes can be continuous, batch or semi-batch.

- What is **control?**

  " Control is to maintain desired conditions in a system by adjusting selected input variables of the system"

Measure → Decide → Correct

- What is **"Process Dynamics"**
- refer to unsteady-state (change with time) process behavior.

- Steady state: variables do not change with time
- Unsteady state: variables change with time

- What is **"Instrumentation"**

  - refer to a device or group of devices used for direct reading or, when using many sensors.

  - deals with the design, configuration and automation of systems.

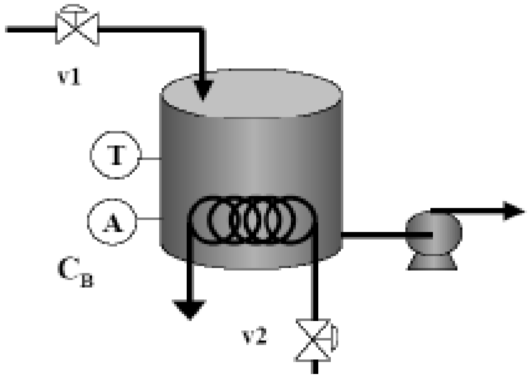
  - part of a complex industrial control system in such as chemical industry, oil & gas plant, manufacturing industry, vehicles and transportation

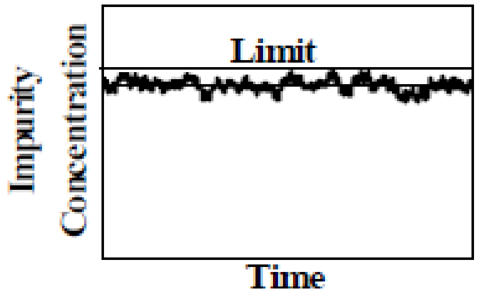
Role of process dynamics and control in industry

- When I run a kinetics experiment, how do I maintain the temperature and level at desired values?

- How do I manufacture products with consistently high quality when raw material properties change?

- How much time do I have to respond to a dangerous situation?





1.2 Control objective and application

Review on objective of a process plant;

- Purpose:

  Process plants transform raw materials into useful products

- Plant Objectives:

  1. *Plants must satisfy production Specification*
     - Good quality products
     - Minimal pollution-noise, air, water, safety standards
  2. *Plant must make profit*
  3. *Safety for the equipment, workers, surrounding and hence everybody.*

How to achieve these objectives?

A process must be designed and operated in such a way that;

- It remain *safe*
- It constantly produces the desired amounts of *high quality product*
- It is *profitable*

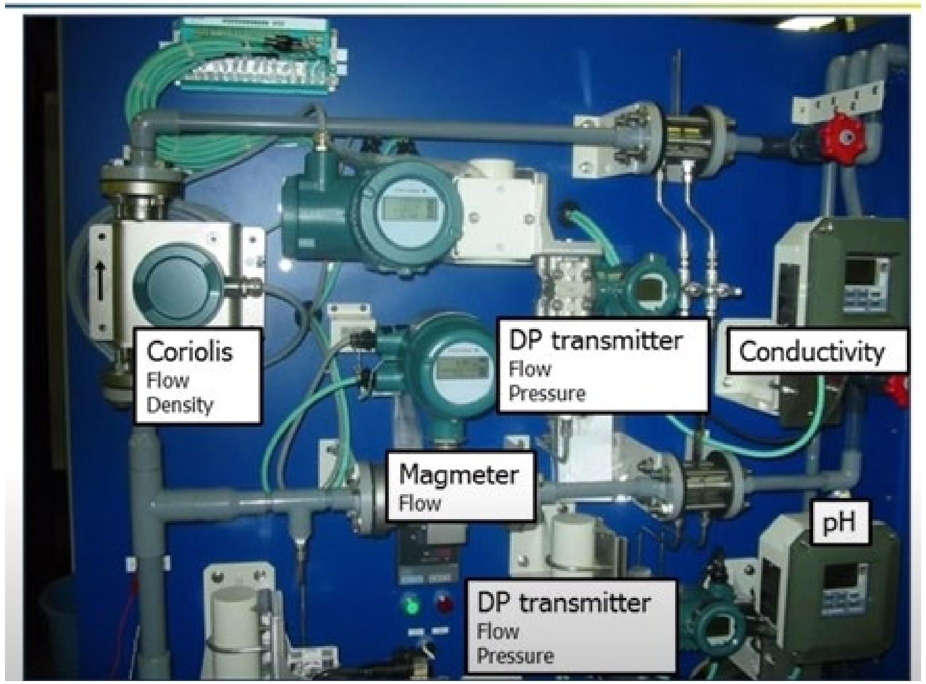
A process instrument must therefore be:

- Safe to use in given process conditions
- As accurate and reliable as possible
- Selected to maximize return on investment (ROI)

An instrument should be selected according to:

- The process variable
- The process application

- ***Process Variables*** are such as temperature, pressure, flow, level, pH and compositions are measured and controlled.
- ***Process control industrial applications*** involve with controlling fluids; liquids, gases, dry solids, and slurry mixtures. Industrial applications are designed to make a profit so improving process control improves profits.



- *Example; Tubular Heat Exchanger, Continuous stirred tank reactor (CSTR), Thermal cracking furnace, Multi-component distillation column, Stir-tank Blending system, Liquid storage, Flash tank, Fuel oil storage and others..*

*Overview on process control and instrumentation with application: https://drive.google.com/drive/folders/1H8A0vO-xnD1A3T662ihdyCKDPnaCbCz4

1.3 Process control variables and problem

The process control problem has been characterized by identifying ***three important types of process control variables***, which is a critical step in developing a control system.

1. Controlled variables – CV or *Process Value/PV*

   these are the variables which quantify the performance or quality of the final product, which are also called *output/measured* variables//Set-point.

2. Manipulated variables – MV

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

3. Disturbance variables – DV

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

Where Do Disturbances Come From?

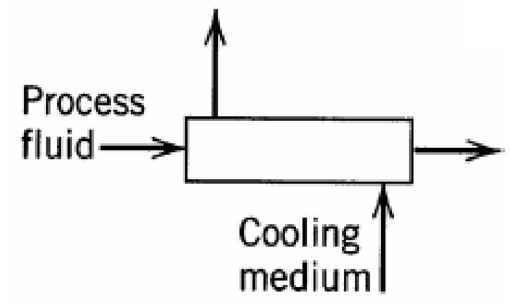
- Variation in composition of incoming raw materials (eg mineral rock, oil/gas, waste water)
- Weather – hot, cold, dry, humid, summer vs winter, pollution levels
- Gradual buildup of scale etc inside the process (eg heat exchanger fouling)
- Unexpected surges due to malfunctions, wear & tear, in pumps, animals!, valves, equipment
- **Process never works “perfectly”!!**

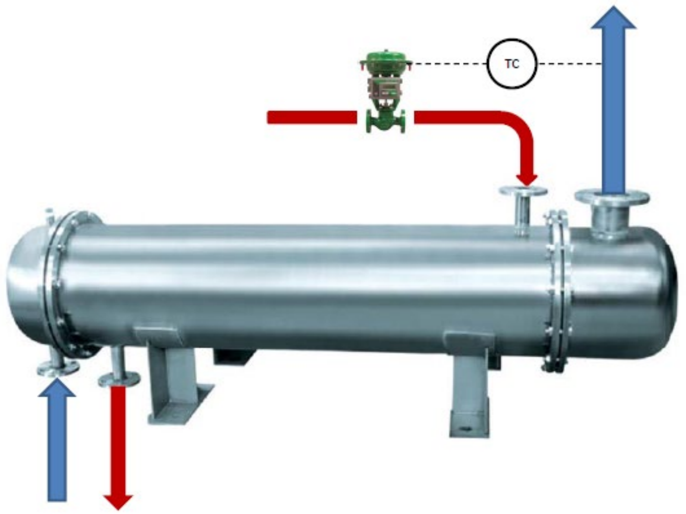
Control Terminology

- **Control:** maintain desired conditions by adjusting variables in the system
- **Input:** Variable that causes a change (not always same as a physical input)
- **Setpoint (SP)**: desired value or range for a controlled variable
- **Process value (PV *or CV*):** the actual value of the variable (measure variable)
- **Sensor:** physical measurement device that senses the physical changes occurs in the surrounding and produces an electric signal
- **Transmitter:** device used to change the sensing input (from sensor) converted into a signal (pneumatic and electric signals) that can be read by the controller.
- **Controller**:
  - Calculates difference between Process value (PV) value reported by the sensor, and the desired set-point (SP) and decides how much to adjust the output variable *(the "brain")*
- **Final control element:** the physical equipment used to adjust the controlled variable. - Usually a control valve

Process control problem

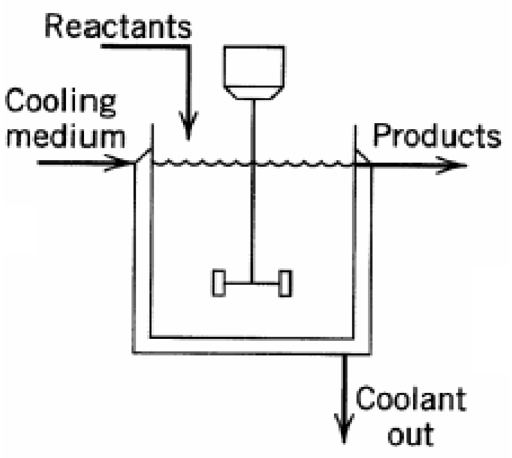
1. Tubular Heat Exchanger

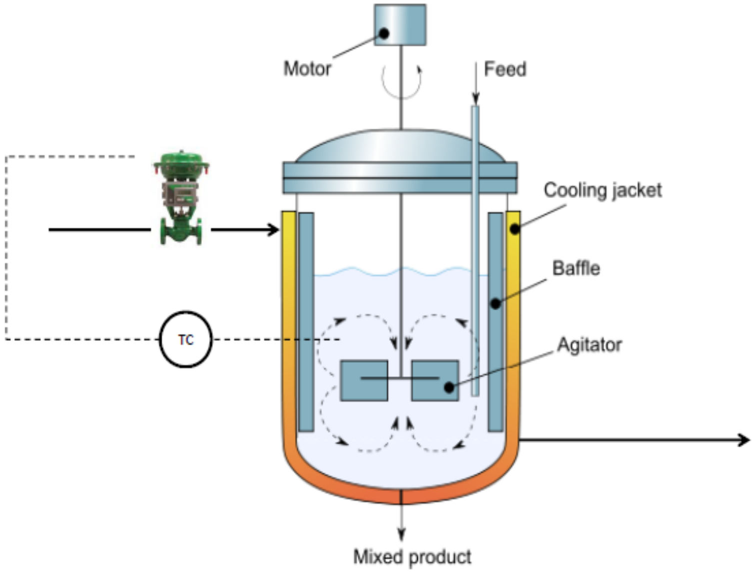




- *Control Variable* : The exit temperature of the process fluid
- *Manipulating variable*: the cooling water flow rate.
- *Disturbances variable*: Variations in the inlet temperatures and process fluid flow rate.

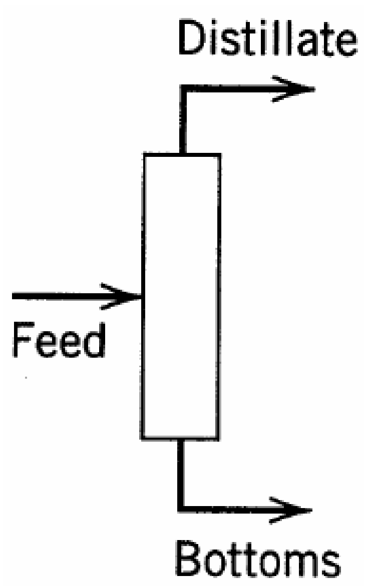
2. Continuous Stirred Tank Reactor (CSTR)

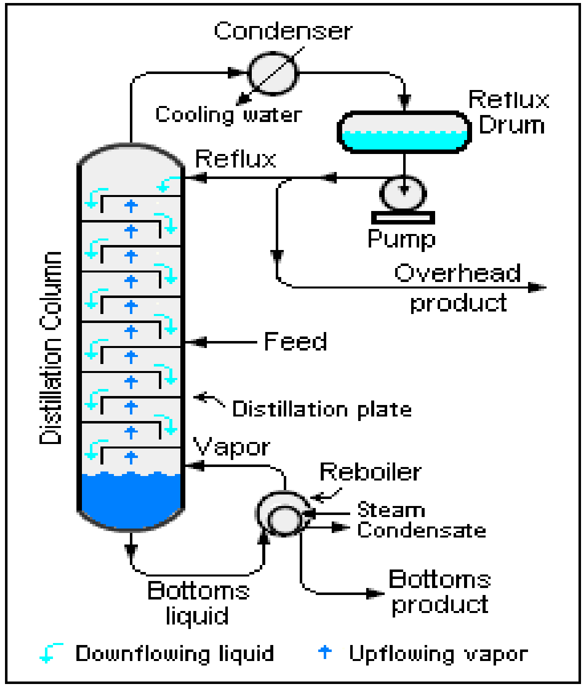




- *Control Variable* : The temperature of the reaction mixture/tank/product
- *Manipulating variable*: rate of the coolant in a jacket or cooling coil.
- *Disturbances variable*: The feed conditions (composition, flow rate, and temperature).

3. Distillation Column





- *Control Variable* : Distillate composition
- *Manipulating variable*: the reflux flow rate or the distillate flow rate.
- *Disturbances variable*: The feed conditions

Active Learning-Group work discussion (Tutorial 1 Part 1)

Find and discuss the meaning for the following term within your group formed using additional information from internet/book resources;

Group A

- Load variable
- Process value
- Hardware
- Control loop
- Signal
- *Heat exchanger

Group B

- Set point
- Process variable
- Manipulated variables
- Disturbance variables
- Controlled variables
- *Thermal cracking furnace

Group C

- Dynamic system
- Steady- state
- Instrumentation system
- Transmitter
- Sensor/ transducer
- *Distillation column

Group D

- Actuator
- Final control element
- Composition
- Flowrate
- Concentration
- *CSTR

Group E/F

- Feedback control
- Feedforward control
- Oscillatory
- Response
- Compensate
- *Evaporator

- Form a group of 6
- 5 terms per group
- Refer to smartv3 for complete tutorial part 1 question

Put your group answer in the *PADLET.*
https://padlet.com/norsuhadatnordin/689f9nxkjn9w0pze

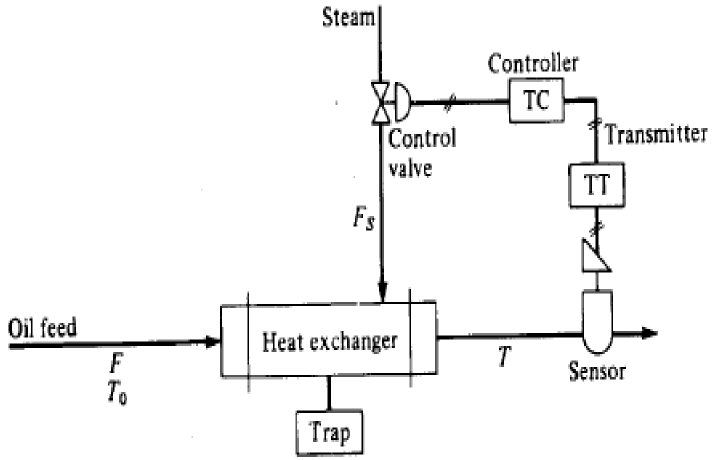
1.4 Typical control loop and strategy

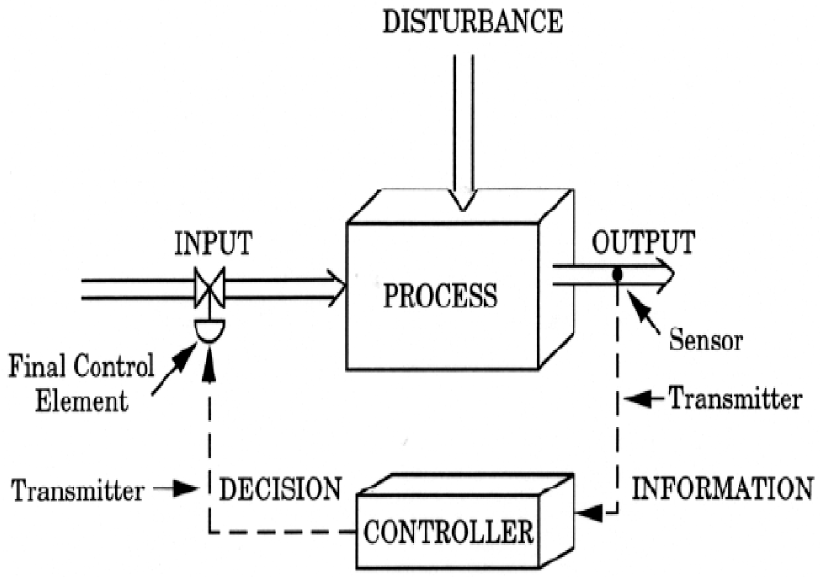
Control loop and hardware element

Control loop	General *control hardware* element

- ***Common control loop;***

Flow, level, pressure, temperature and composition loops



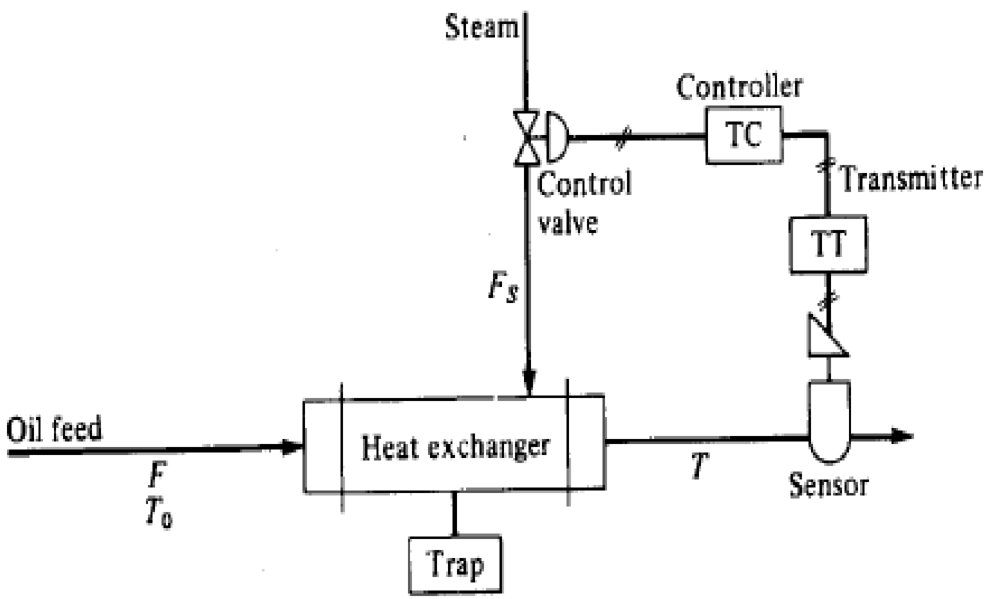


Components of control loop/hardware element;

- A sensor, transmitter, controller and final control element

Terminology in a control loop;

- **First letter:**
- A= Analyzer/composition
- F = flowrate
- L = level in vessel
- P = pressure
- T= temperature



- **Second letter:**
- C = controller: a control calculation is performed
- T= transmitter: a variable is measured and transmitted
- I = Indicator: a variable is measured and displayed

Basic process control terminology: https://drive.google.com/drive/folders/1H8A0vO-xnD1A3T662ihdyCKDPnaCbCz4

Example: Level Control Loop

The following figure show a control loop to maintain the liquid level in the tank. Note that the feed flow rate is changing over the time of the process. Identify the control objective and three main important variables.

Control Objective:

maintain the liquid level at desired value

Controlled Variables/Process Value:

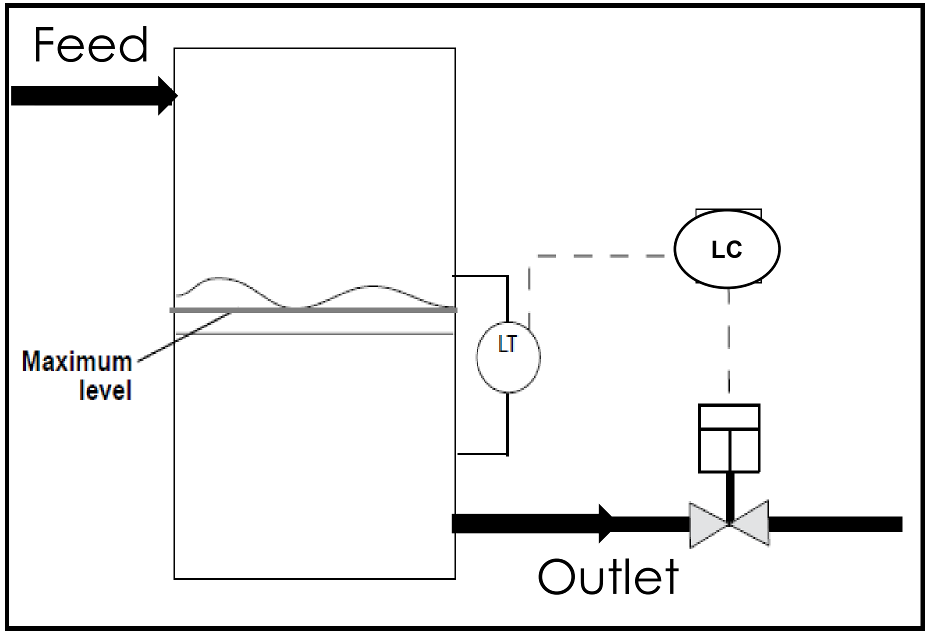
Level of liquid

Manipulated variables:

Outlet flow rate

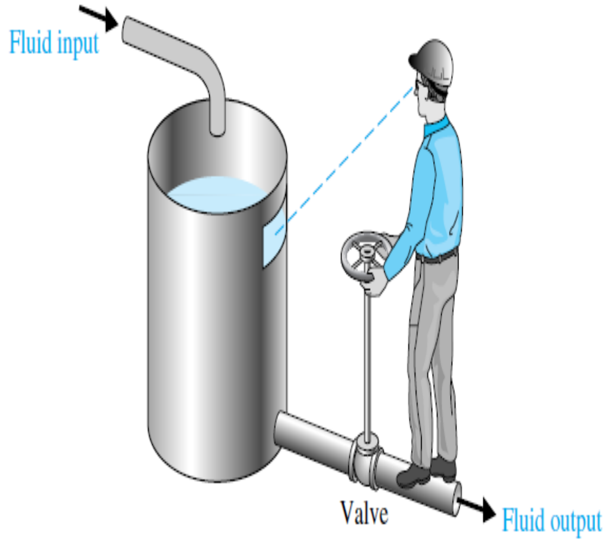
Disturbance variable:

Feed flowrate



A Simple Control Loop

Control mechanism:



Level control

Measure

❖In the figure, a level transmitter (LT) measures the level in the tank and transmits a signal associated with the level reading to a controller (LIC).

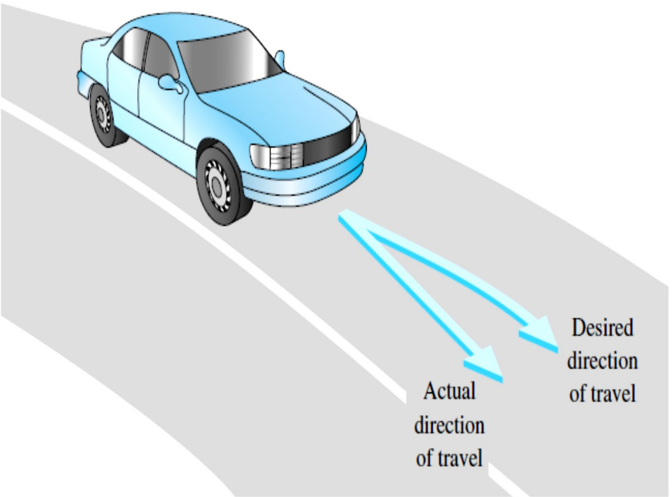
❖The controller compares the reading to a predetermined value

Decision

❖The controller then sends a decision signal to the device (valve) that can bring the tank level back to a desired level

Action

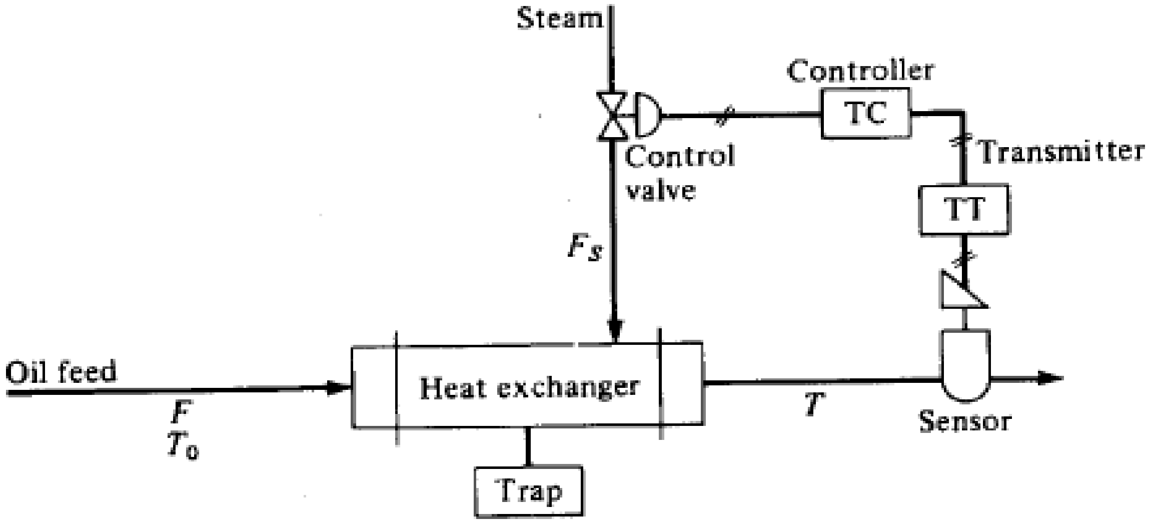
❖The valve is then adjusted (open or close) to control amount of liquid flow out from the tank.



Manual driving control

Overview on control system

"We want to control the temperature of oil leaving the heat exchanger"….How to control??



1. A thermocouple is inserted in a thermowell in the exit oil pipe.
2. Thermocouple wires are connected to a "temperature transmitter" that converts the millivolt output into a 4- to 20 mA signal.
3. This signal sent to a temperature controller.
4. The temperature controller opens the steam valve if more steam is needed or closes it a little if the temperature is too high.

Home appliance control loop system;
https://drive.google.com/drive/folders/1H8A0vO-xnD1A3T662ihdyCKDPnaCbCz4

Illustrative Example: Blending System

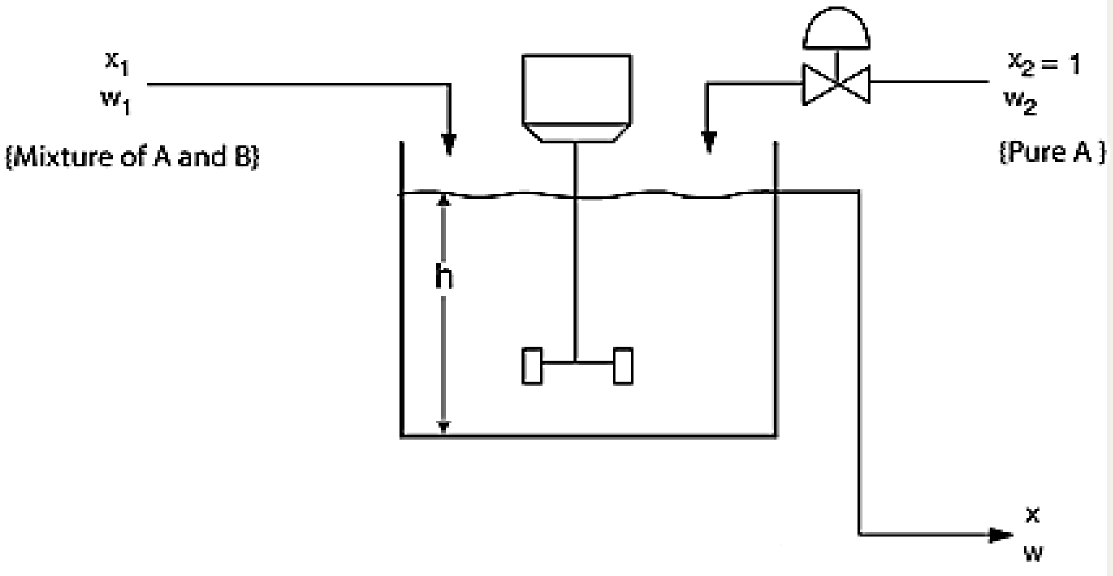


Figure 1.3. Stirred-tank blending system.

Notation:

- w_1, w_2 and w are mass flow rates
- x_1, x_2 and x are mass fractions of component A

Assumptions:

- w_1 is constant
- x_2 = const. = 1 (stream 2 is pure A
- Perfect mixing in the tank

- **Control Objective:**

- Keep x at a desired value (or "set point") x_{sp}, despite variations in $x_1(t)$. Flow rate w_2 can be adjusted for this purpose.

- **Terminology:**

- Controlled variable (or "output variable"): x
- Manipulated variable (or "input variable"): w_2
- Disturbance variable (or "load variable"): x_1

- ***Design Question***. What value of $\overline{w}_2$ is required to have $\overline{x} = x_{SP}$?

Mass Balance Equation

- **Overall balance:**

$$0 = \bar{w}_1 + \bar{w}_2 - \bar{w} \qquad (1\text{-}1)$$

- **Component A balance:**

$$\bar{w}_1\bar{x}_1 + \bar{w}_2\bar{x}_2 - \bar{w}\bar{x} = 0 \qquad (1\text{-}2)$$

- (The overbars denote nominal steady-state design values.)

- At the design conditions, $\bar{x} = x_{SP}$. Substitute Eq. 1-2, $\bar{x} = x_{SP}$ and $\bar{x}_2 = 1$, then solve Eq. 1-2 for $\bar{w}_2$:

$$\bar{w}_2 = \bar{w}_1 \frac{x_{SP} - \bar{x}_1}{1 - x_{SP}} \qquad (1\text{-}3)$$

- Equation 1-3 is the design equation for the blending system.
- If our assumptions are correct, then this value of $\overline{w}_2$ will keep $\overline{x}$ at x_{SP} . But what if conditions change?

•***Control Question.*** *Suppose that the inlet concentration* x_1 *changes with time. How can we ensure that x remains at or near the set point* x_{SP} *?*

•As a specific example, if $x_1 > \overline{x}_1$ and $w_2 = \overline{w}_2$, then $x > x_{SP}$.

Some Possible Control Strategies:

Method 1 → ***Measure x and adjust w_2.(Feedback)***

- Intuitively, if x is too high, we should reduce w_2;
- Manual control vs. automatic control
- Proportional feedback control law,

$$w_2(t) = \bar{w}_2 + K_c\left[x_{SP} - x(t)\right] \qquad (1\text{-}4)$$

1. where K_c is called the controller gain.
2. $w_2(t)$ and $x(t)$ denote variables that change with time t.
3. The change in the flow rate, $w_2(t) - \bar{w}_2$, is proportional to the deviation from the set point, $x_{SP} - x(t)$.

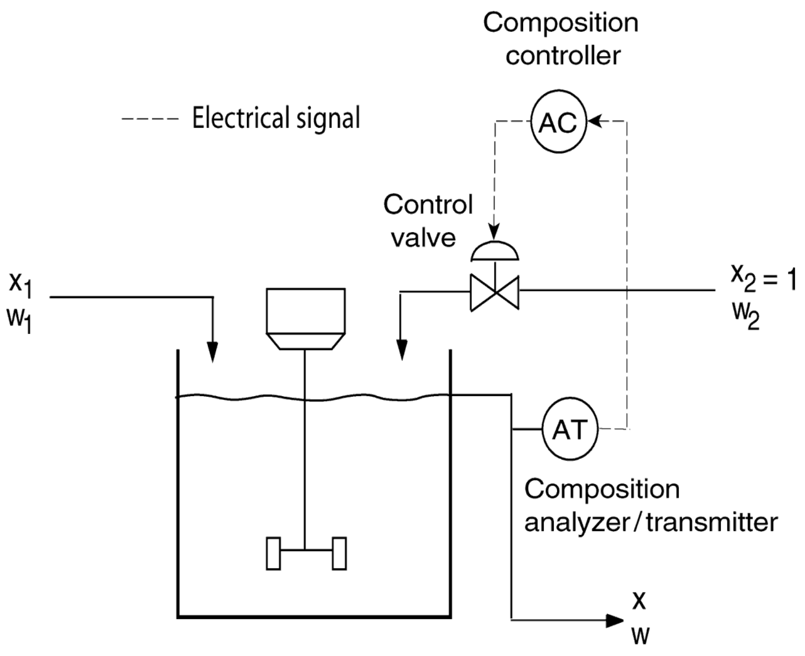


Figure 1.4. Blending system and Control Method 1.

Method 2 → *Measure x_1 and adjust w_2.(Feedforward)*

- Thus, if x_1 is greater than $\bar{x}_1$, we would decrease w_2 so that $w_2 < \bar{w}_2$.
- ***One approach***: Consider Eq. (1-3) and replace $\bar{x}_1$ and $\bar{w}_2$ with $x_1(t)$ and $w_2(t)$ to get a control law:

$$w_2(t) = \bar{w}_1 \frac{x_{SP} - x_1(t)}{1 - x_{SP}} \qquad (1\text{-}5)$$

- Because Eq. (1-3) applies only at steady state, it is not clear how effective the control law in (1-5) will be for transient conditions.

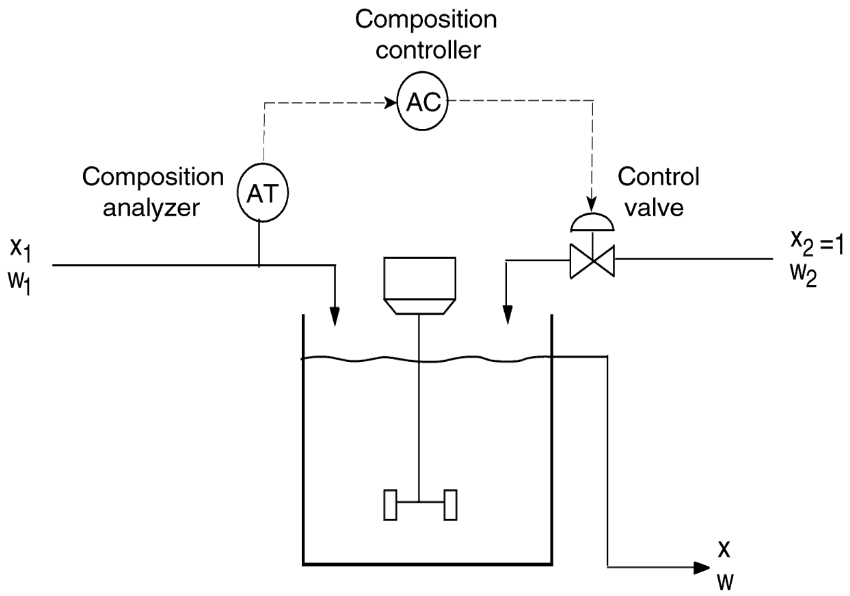


Figure 1.5. Blending system and Control Method 2.

Method 3 → *Measure x_1 and x, adjust w_2.*

- This approach is a combination of Methods 1 and 2.

Classification of Control Strategies: Feedback & Feedforward

1. Feedback Control:

measure the controlled variable to influence an input variable, which compensate (corrective) After controlled variables are affected

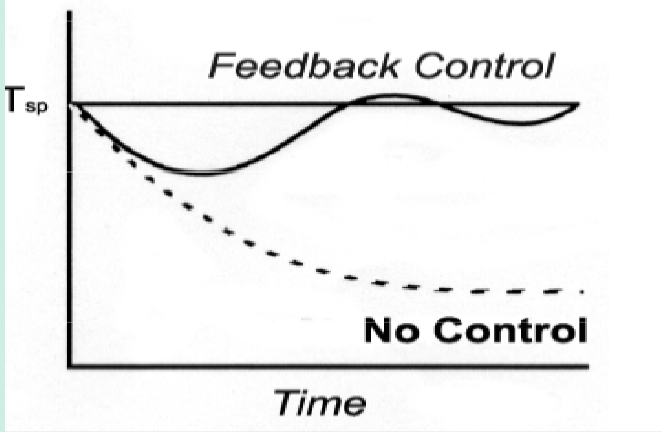
2. Feedforward Control:

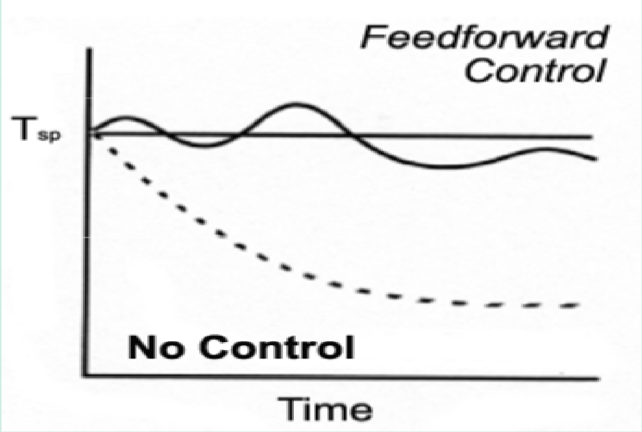
measure a disturbance variable in the input and compensate (corrective) Before the controlled variables are affected

Table. 1.1 Control Strategies for the Blending System

Method	*Measured Variable*	*Manipulated Variable*	*Category*
1	x	w_2	FB[a]
2	x_1 (disturbance)	w_2	FF
3	x_1 (disturbance) and x	w_2	FF/FB

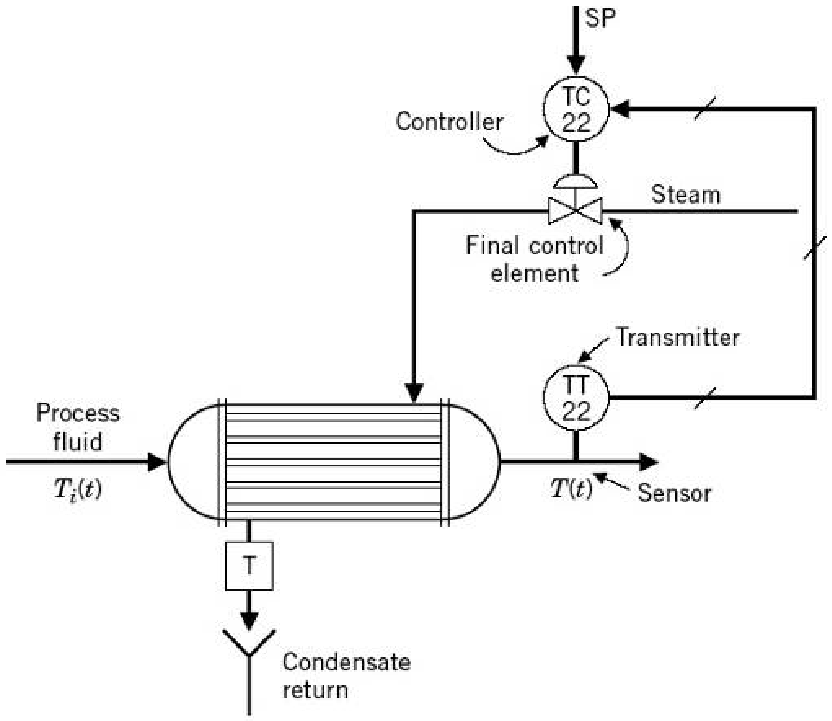
	Feedback	Feedforward
Advantages	• Corrective action is taken regardless of the source of the disturbance.	• Correct for disturbance before it upsets the process
Disadvantages	• Adjustment takes place only after the controlled variable is affected significantly	• No corrective action for unmeasured disturbances.
Response	Very oscillatory responses, or even instability	Faster response to disturbances in the feed.



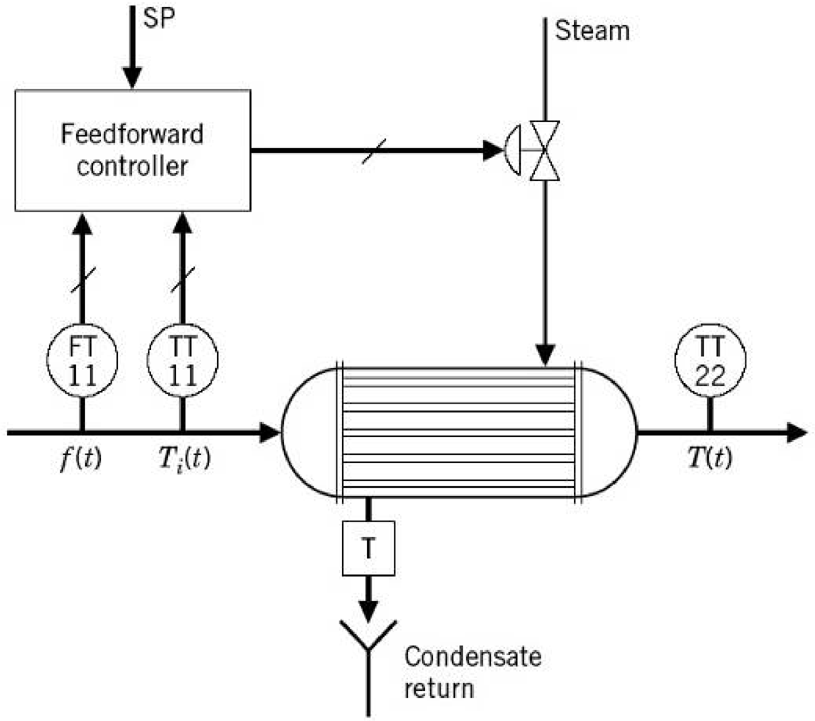


Example on Heat Exchanger control system: Feedback, Feedforward & FB/FF Strategy

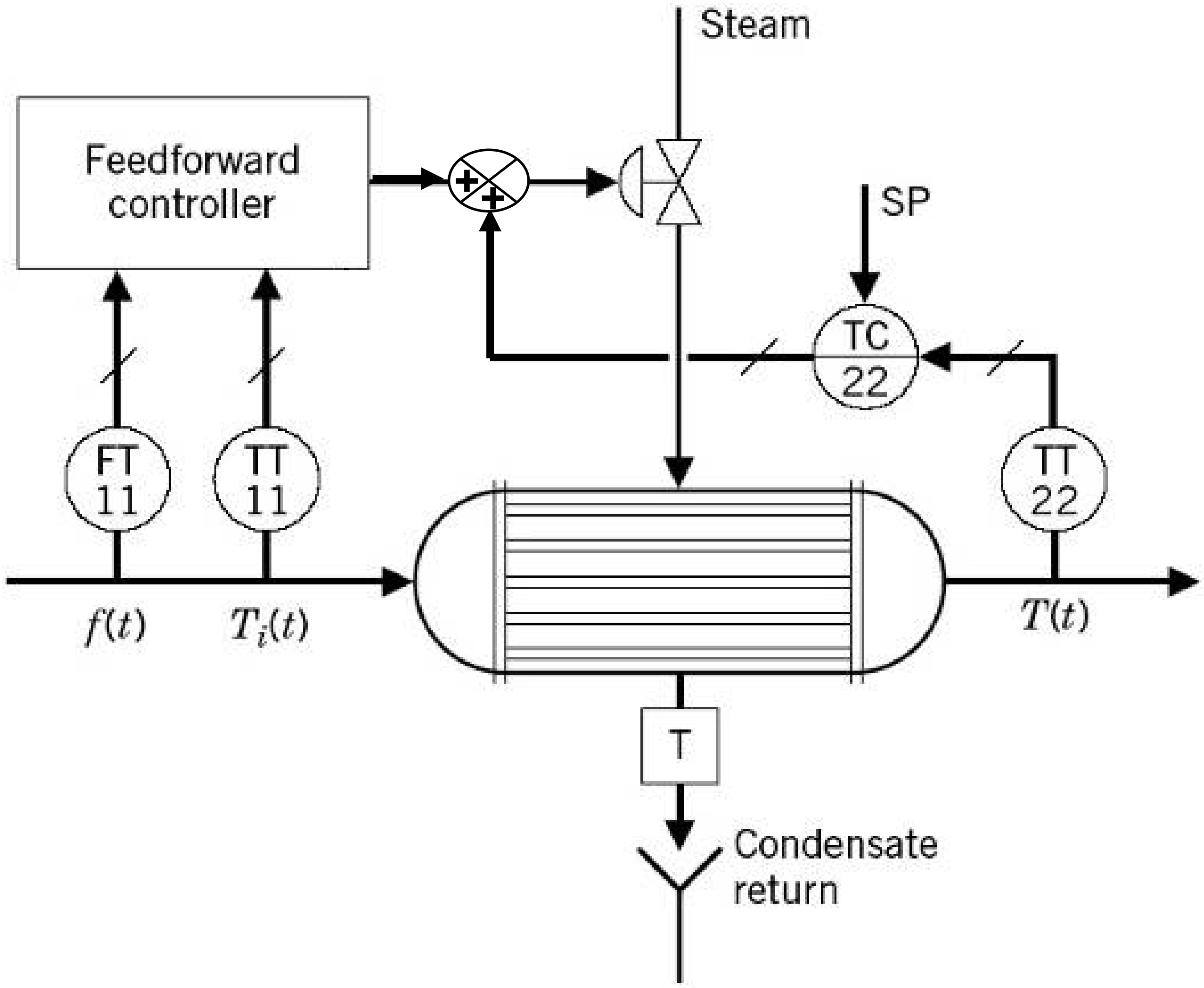
Feedback control



Feedforward control

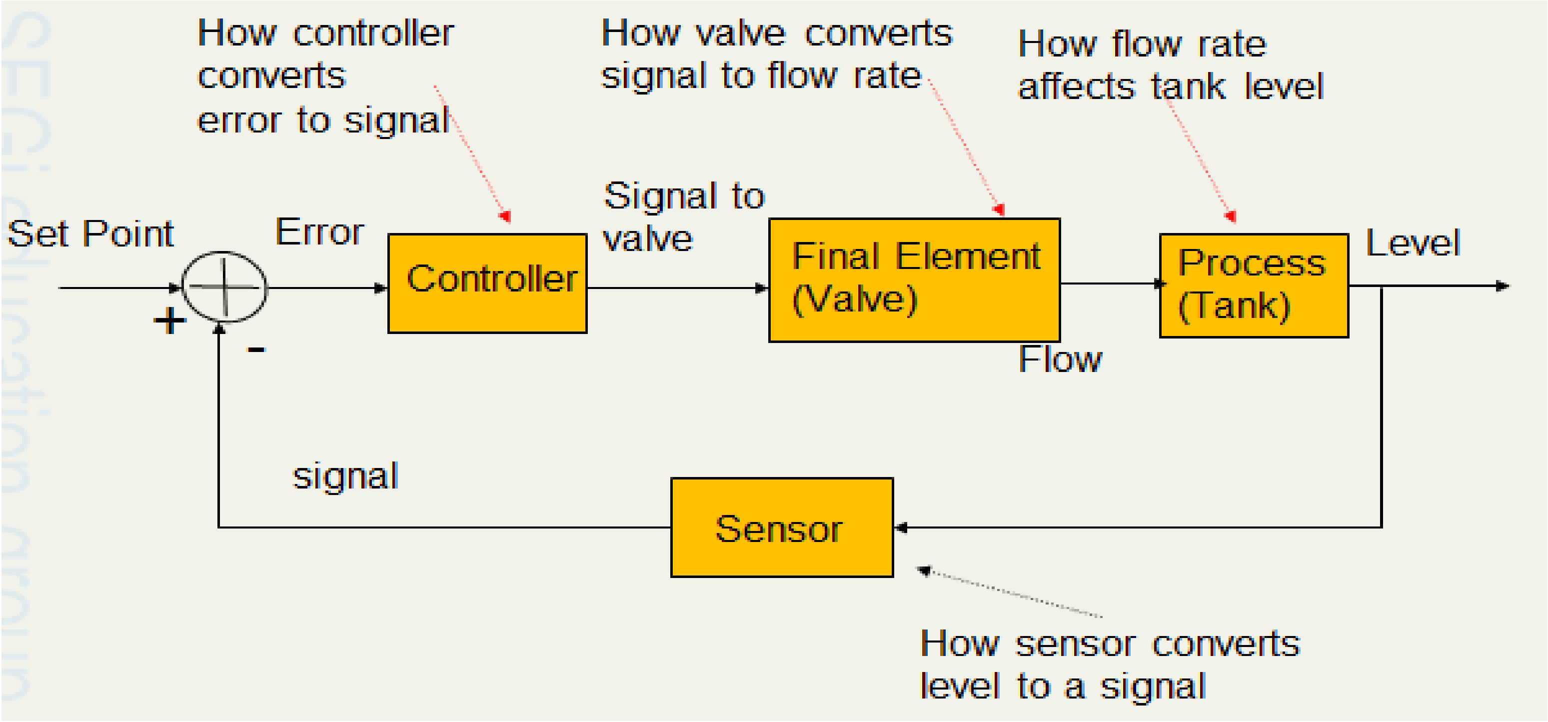


Feedback & Feedforward control



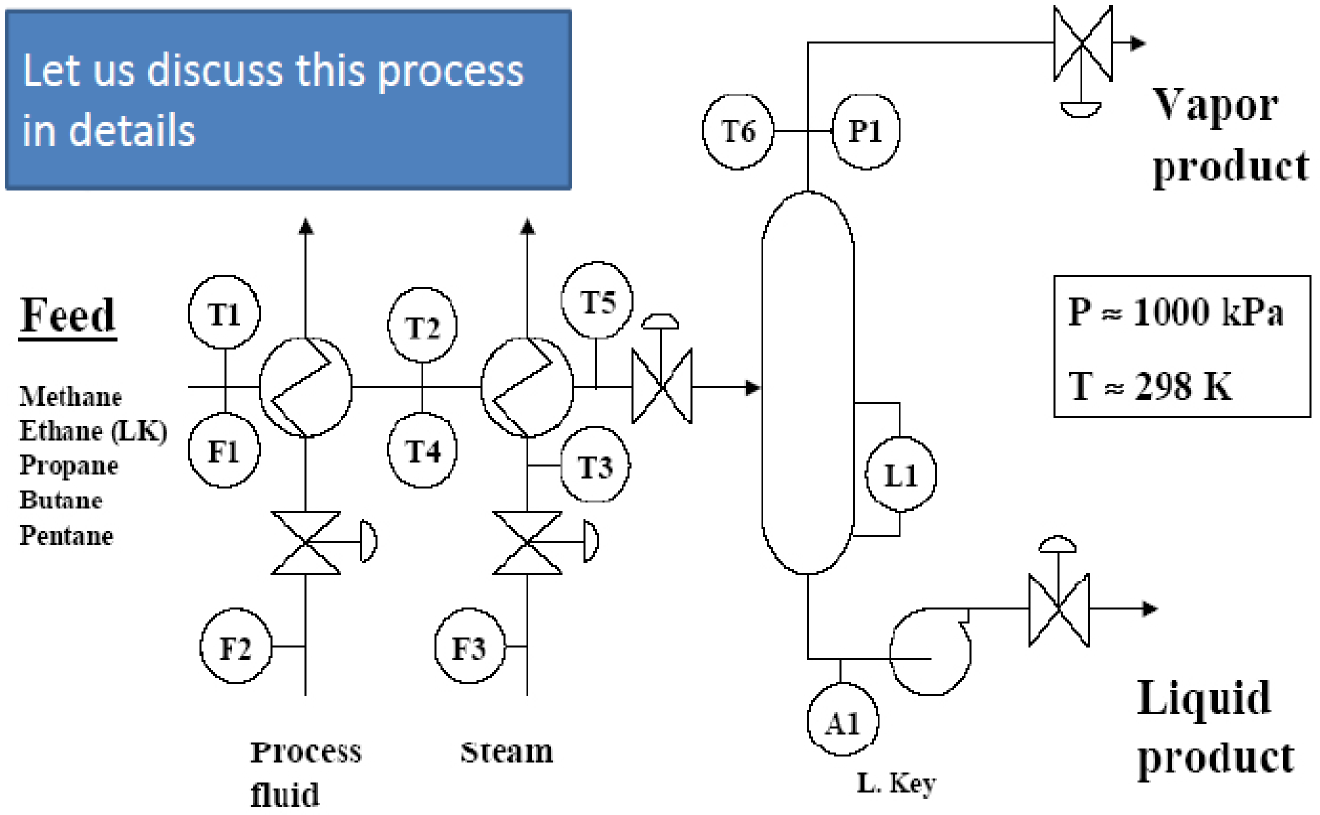
Overview on Block Diagram

- Block diagram shows process variables and control signals
- Each block contains dynamic response model (process, controller)
- Negative feedback – output linked to input (like a recycle loop)
- Sensors and valves also have dynamics, and may need to account for these.

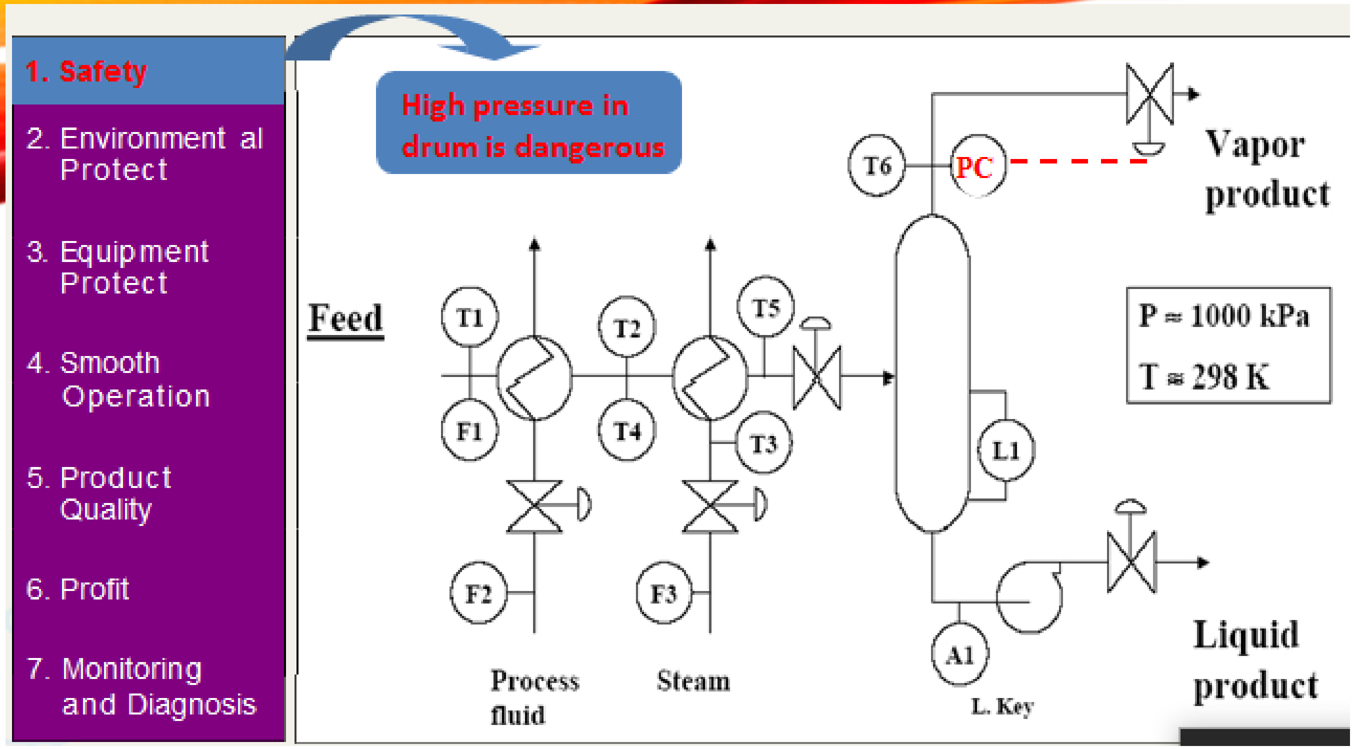


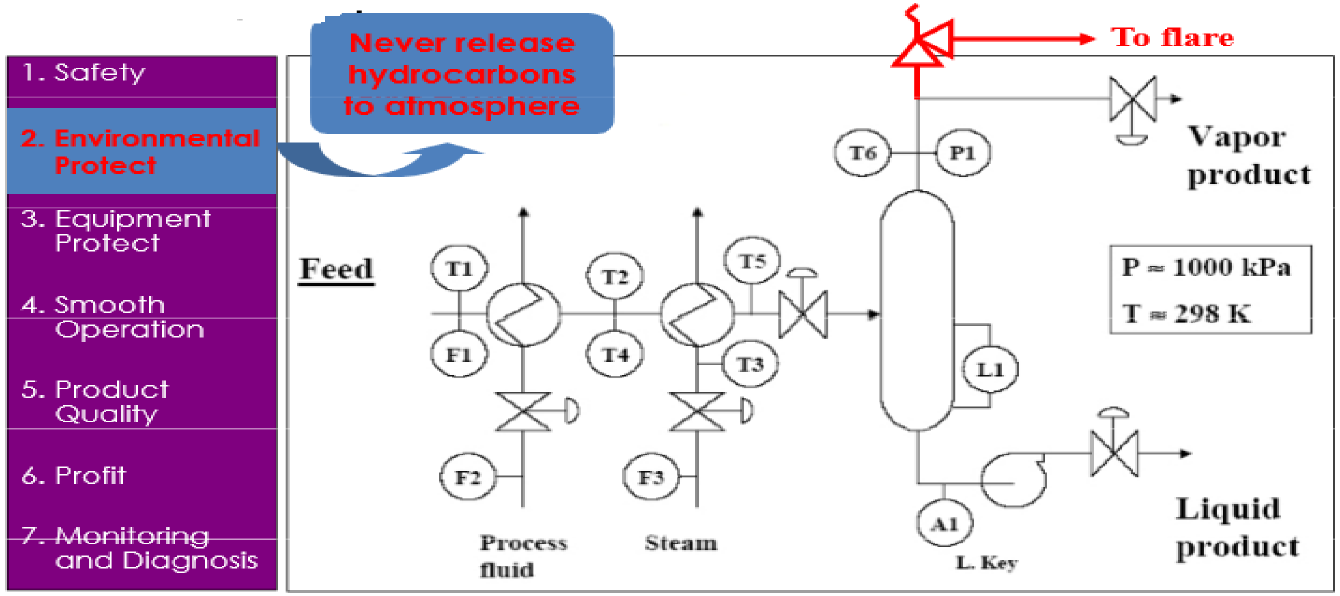
Summary of Control objectives & Strategy on control loop decision

Let us discuss this process in details

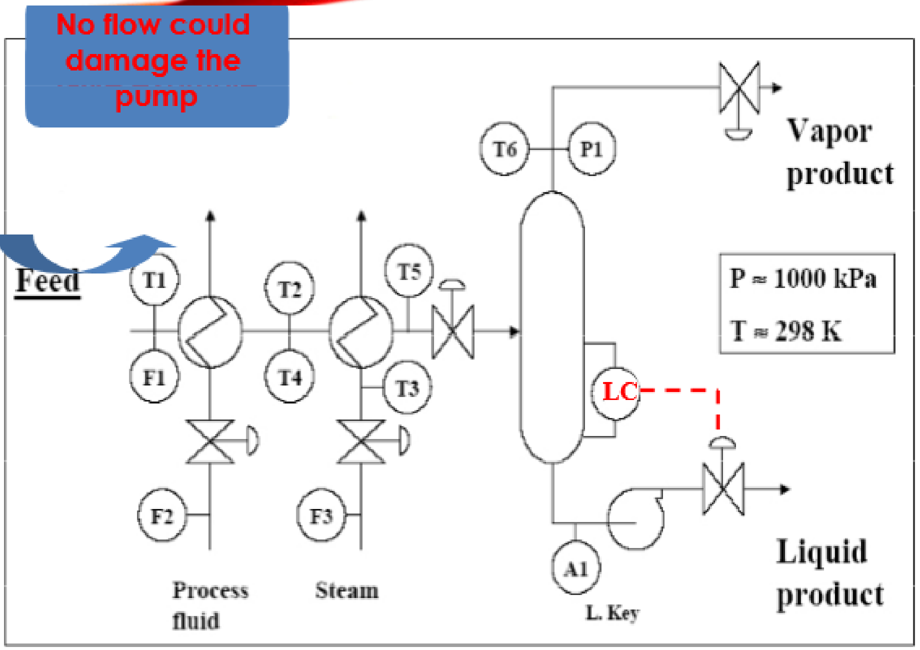


Flash Separation

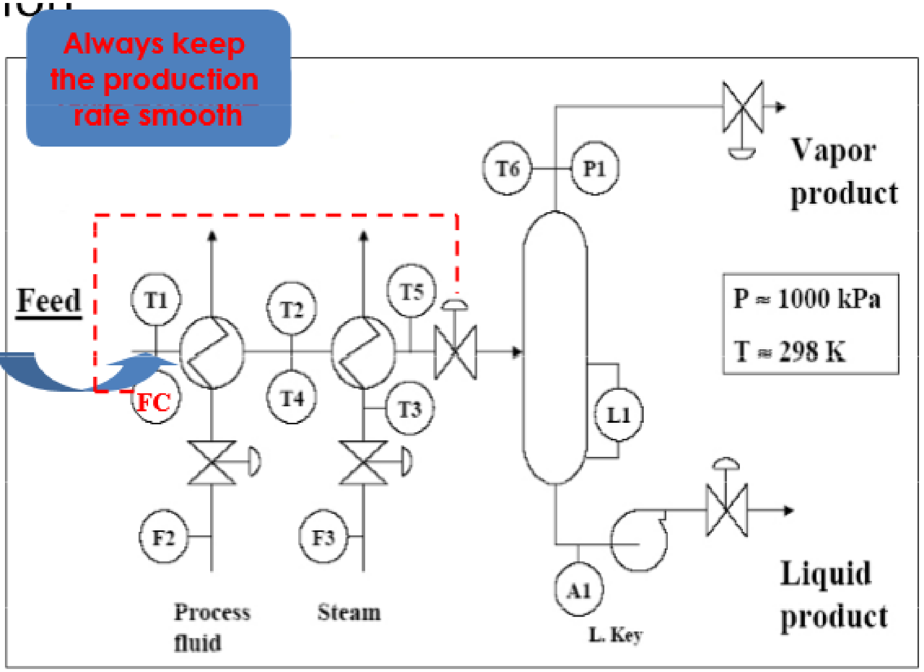

1. Safety
2. Environment al Protect
3. Equipment Protect
4. Smooth Operation
5. Product Quality
6. Profit
7. Monitoring and Diagnosis
High pressure in drum is dangerous
Feed
T1
T2
T5
T6
PC
F1
T4
T3
L1
F2
F3
A1
Process fluid
Steam
L. Key
Vapor product
Liquid product
P ≈ 1000 kPa
T ≈ 298 K


1. Safety
2. Environmental Protect
3. Equipment Protect
4. Smooth Operation
5. Product Quality
6. Profit
7. Monitoring and Diagnosis
Never release hydrocarbons to atmosphere
To flare
Feed
T1
T2
T5
T6
P1
F1
T4
T3
L1
F2
F3
A1
Process fluid
Steam
L. Key
Vapor product
Liquid product
P ≈ 1000 kPa
T ≈ 298 K

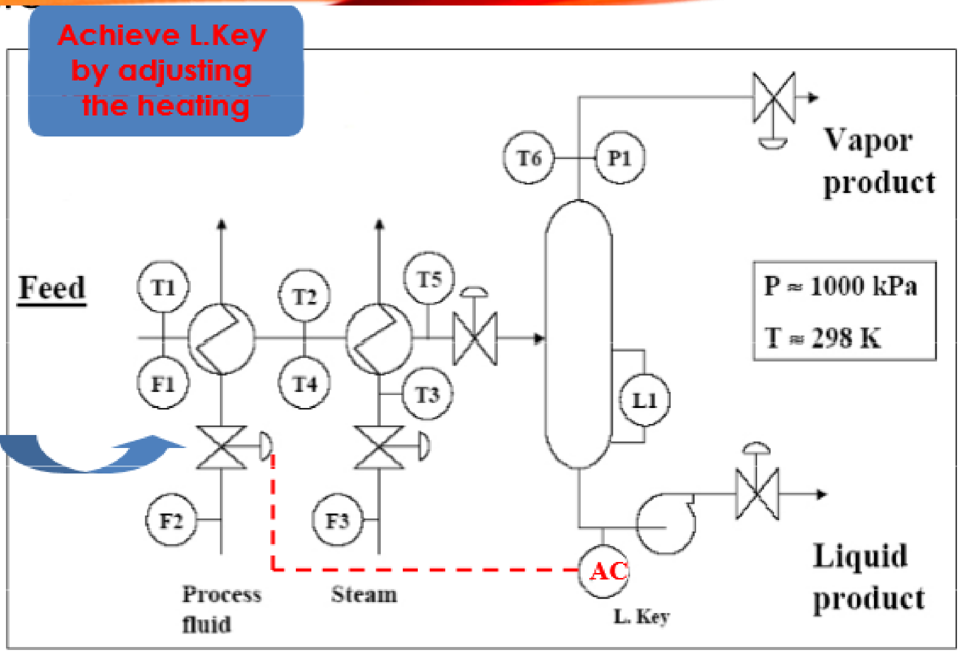
1. Safety
2. Environmental Protect
3. **Equipment Protect**
4. Smooth Operation
5. Product Quality
6. Profit
7. Monitoring and Diagnosis



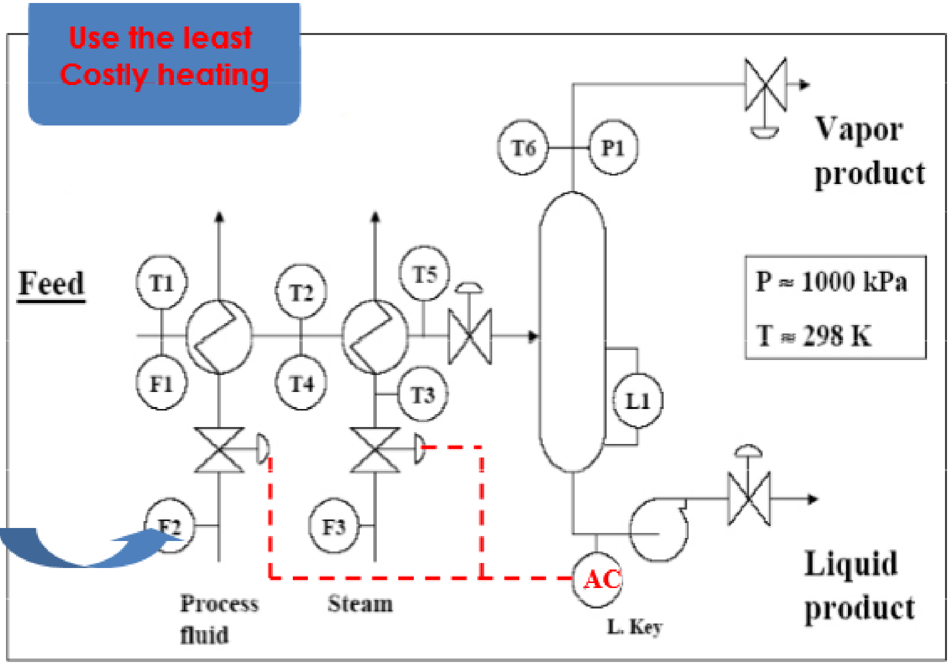
1. Safety
2. Environmental Protect
3. Equipment Protect
4. **Smooth Operation**
5. Product Quality
6. Profit
7. Monitoring and Diagnosis



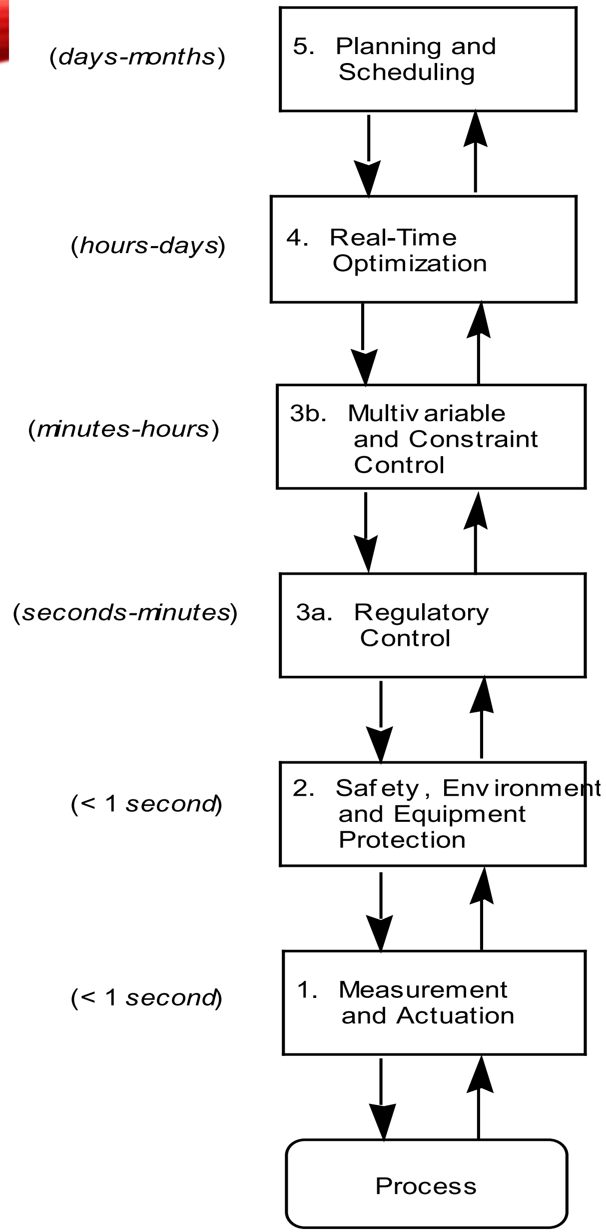
1. Safety
2. Environmental Protect
3. Equipment Protect
4. Smooth Operation
5. **Product Quality**
6. Profit
7. Monitoring and Diagnosis



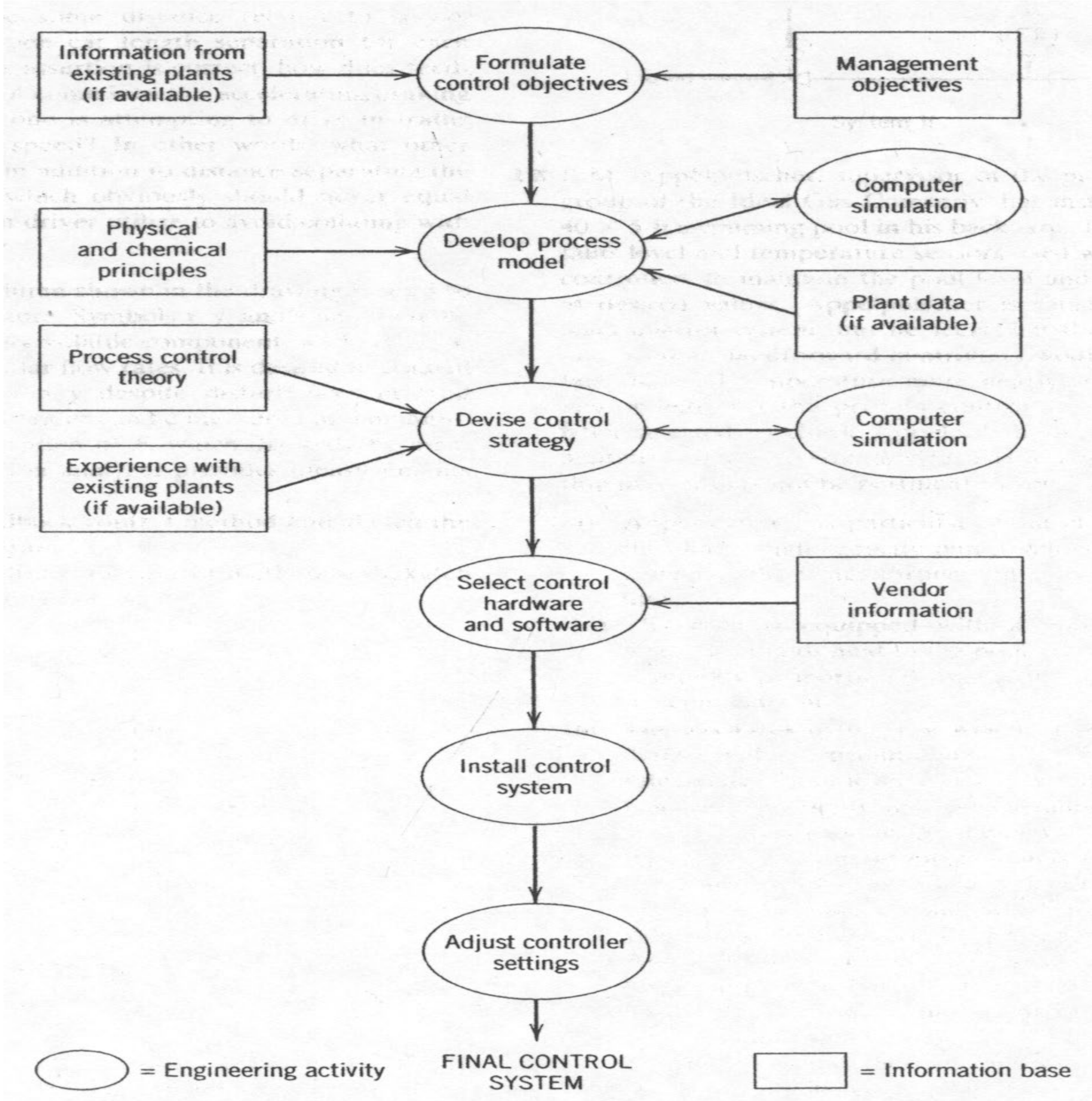
1. Safety
2. Environmental Protect
3. Equipment Protect
4. Smooth Operation
5. Product Quality
6. **Profit**
7. Monitoring and Diagnosis



Hierarchy of process control activities



Major steps in control system development



- ***Review lesson for Chapter 1 (pop Quiz)*** : *https://kahoot.it/*

THANK YOU