Process Dynamics and Control

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Chapter One
Introductory Concepts

- **What is Chemical Engineering?**

  - **Chemical Engineering**: is a branch of engineering which is concerned with the production of bulk materials from basic raw materials in a most economic way by chemical means.

- **What are some specific job functions of Chemical Engineers?**

  - apply the principles of chemistry, biology, physics, and math to solve problems that involve the production or use of chemicals, fuel, drugs, food, and many other products.

  - design processes and equipment for large-scale manufacturing, plan and test production methods and byproducts treatment, and direct facility operations.

- improve food processing techniques, and methods of producing fertilizers, to increase the quantity and quality of available food.

- construct the synthetic fibers that make our clothes more comfortable and water resistant

- develop methods to mass-produce drugs, making them more affordable

- create safer, more efficient methods of refining petroleum products, making energy and chemical sources more productive and cost effective

- develop solutions to environmental problems, such as pollution control and remediation

- used to make or improve just about everything you see around you

- Optimization and control of industrial operations

- The two main subjects of this course are:
  - process dynamics (PD) and
  - process control (PC)

- The term PD refers to unsteady-state (or transient) process behavior.

- The primary objective of PC is
  - To maintain a process at the desired operating conditions
  - To keep the safety and efficiency
  - To satisfy environmental and product quality requirements.

- The subject of process control is concerned with how to achieve these goals.

What is a process?

- **Process** is the methods of changing or refining raw materials to create end products using chemical and physical operations.

- In practice, the term process tends to be used for both the processing operation and the processing equipment.

- The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product.

- A **chemical plant** is an arrangement of processing units (reactors, heat exchangers, pumps, distillation columns, absorbers, evaporators, tanks, etc.), integrated with one another in a systematic input feedstock) into desired products using available sources of energy, in the economic way and rational manner.

- A **process variable** is a condition of the process fluid that can change the manufacturing process in some way.

- Common process variables include:
    - Pressure
    - Flow rate
    - Level
    - Temperature
    - Compositions

- The **set point** is a value for a process variable that is desired to be maintained.

- **Process control** is the methods that are used to control process variables when manufacturing a product.

- For example, factors such as:
  - the proportion of one ingredient to another,
  - the temperature of the materials,
  - how well the ingredients are mixed, and
  - the pressure under which the materials are held can significantly impact the quality of an end product.

- There are three general classes of needs that a control system is called to satisfy:
    - Suppress the influence of external disturbances
    - Ensure the stability of a chemical process
    - Optimize the performance of a chemical process.
- Manufacturers control the production process for three reasons:
    - Reduce variability
    - Increase efficiency
    - Ensure safety

Control loops in the process control industry work in the same way, requiring three tasks to occur:

- Measurement

- Comparison

- Adjustment

**The Importance of Process Control**

- Refining, combining, handling, and otherwise manipulating raw materials to profitably produce end products can be a precise, demanding, and potentially non-hazardous process.

- Small changes in a process can have a large impact on the end result.

- Variations in proportions, temperature, flow rate, turbulence, and many other factors must be carefully and consistently controlled to produce the desired end product with a minimum of raw materials and energy.

- Process control is the tool that enables manufacturers to keep their operations running within specified limits and to set more precise limits to maximize profitability, ensure quality and safety.

- The focus of the engineer must be on the process.

- The dynamic behavior of the individual units and the process as a whole is to be understood.

- It is always the best to utilize the simplest control system that will achieve the desired objectives.

- The design of a process determines how it will respond dynamically

- Any chemical plant consist of various process units which are inter connected with one another in systematic manner.

- In the analysis of plant operation the desired values are determined by control objectives.

- General objective of any plant is:
  - to convert certain raw materials into desired product using available sources of energy.

- Specific objective
  - safety
  - product specification
  - environmental regulations
  - operation constraints
  - Economics (minimum cost and maximum profit)

Classification of Variables in a Chemical Process

- The variables in chemical process are classified into two:

  - **Input variables**: variables that affect the process
  - **Output variables**: variables that are affected by the process

- The input variables can be further classified into the two categories:

  - Manipulated variables: values can be adjusted freely by the human operator
  - Disturbances (load): values can not adjustment by an operator

- The output variables are also classified into the two categories:

  - Measured output variables: values are known by directly measuring them
  - Unmeasured output variables: values cannot be measured directly

External Disturbances
Measured (d)   Unmeasured (d')

Manipulated
Variables
(m)

Processing System

Measured
Outputs
(y)

Unmeasured Outputs (z)
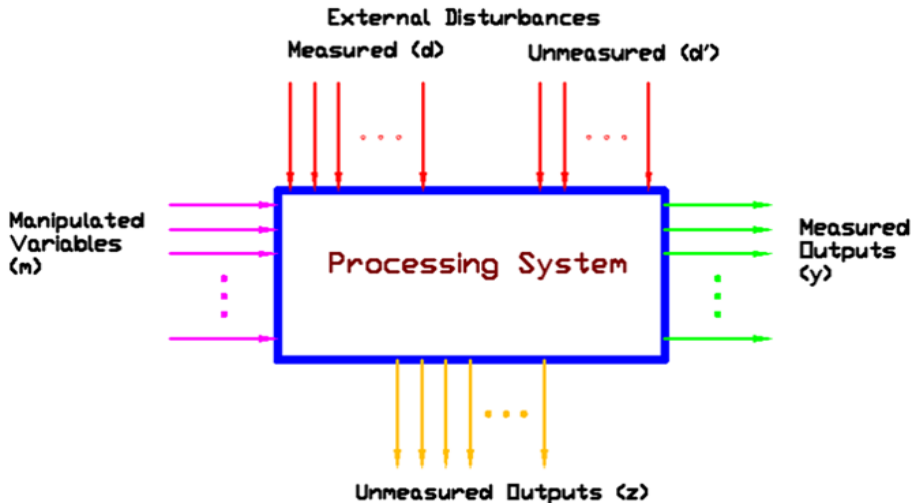
- The main categories of measurements used in process control are process variables.

Design steps of a control system

1) Define Control Objectives: What are the operational objectives that a control system is called to achieve?

2) Identifying and classifying variables: What variables should we measure in order to monitor the operational performance of a plant?

3) Selecting the controller configurations: What is the best control configuration for a given chemical process control situation?

4) Selecting the manipulated variables: What are the manipulated variables to be used in order to control a chemical process?

5) Designing the controllers: How is the information taken from the measurements used to adjust the values of the manipulated variables?

Process Design

- A key factor in control engineering is the design of the process so that it can be controlled well.

- For this purpose systems should be responsive.

- A responsive control system means the controlled variable responds quickly to adjustments in the manipulated variable.

- Frequency and magnitude of disturbances should be reduced.

- There are three most common types of control configurations.

    1) Feedback
    2) Feed forward
    3) Inferential

1) Feedback: measure the controlled variables (output variables) and adjust the manipulated variables.

- The objective is to keep the controlled variables at desired levels (set points).
- Advantage: Corrective action is taken regardless of the source of the disturbance.
- Disadvantage: The controlled variable must be deviate from the set point before corrective action is taken.
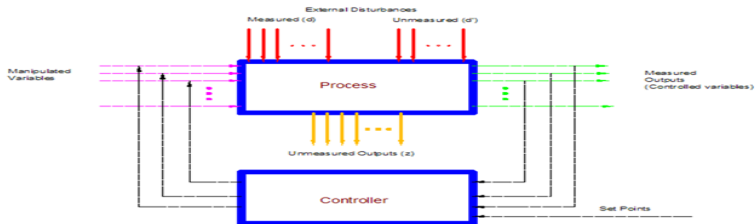
- **2) Feed forward**: measure the disturbances variables and adjust the manipulated variables.
- The objective is to keep the values of the controlled output variables at desired levels.
- Advantages: If all sources of the disturbances are known and these values can be measured accurately. $\Rightarrow$ Perfect Control !
- Disadvantages: No corrective action for unmeasured disturbances.
- In industrial applications, feedfoward control should be used in combination with feedback control.
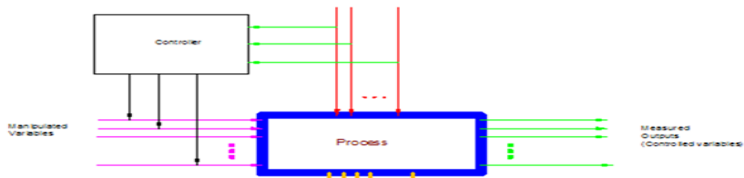
- **3) Inferential**: take secondary measurements and estimate the values of the primary measurements, because the controlled variables are not measured, to adjust the values of the manipulated variables.

- The objective is to keep the (unmeasured) controlled variables at desired levels.

- The estimator uses the values of the available measured outputs, along with the material and energy balances that govern the process, to compute mathematically (estimate) the values of the unmeasured controlled variables.

Example 1: Continuous stirred-tank heater (CSTR)

Assume that inlet temperature changes with time. How can we ensure

that T remains at or near the set point TR?
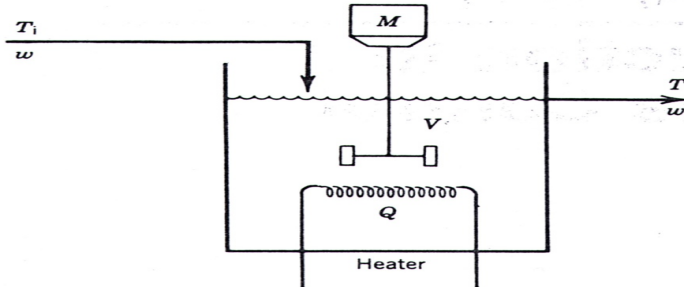
Possible Strategies

1 Measure T and adjust Q or [2] Measure Ti and adjust Q.

3 Measure T and adjust w or [4] Measure Ti and adjust w.

5 Measure T and Ti and adjust Q or

6 Measure T and Ti and adjust w.

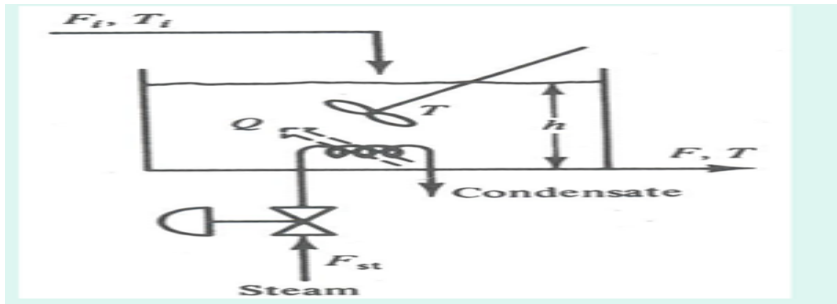7 Place a heat exchanger on the inlet stream.

8 Use a large tank.

Classification

- 1 and 3: Feedback control

- 2 and 4: Feedfoward control

- 5 and 6: Feedfoward-Feedback control

- 7 and 8: Design change

Feedback control configuration
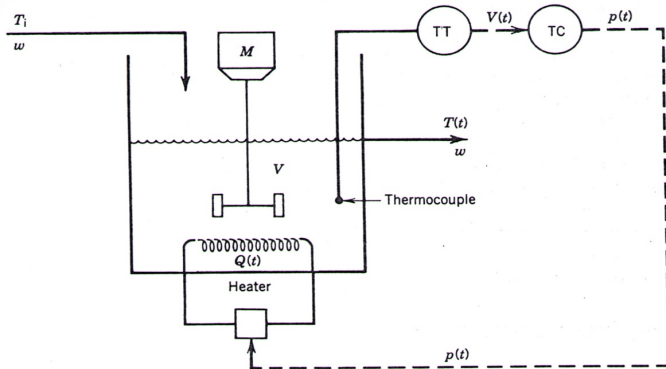
Example 2: Tank heater system Assume that inlet temperature changes with time. How can we ensure that T remains at or near the set point TR?

- Disturbances inputs: Fi and Ti

- Manipulated inputs: Fst

- Measured outputs: V and T

- Fi: flow rate in (m3/min); Ti: inlet temperature (oF)

- Fs: steam mass flow rate (kg/min); Ts: set point temperature

- F: flow rate outgoing liquid

- T: temperature stream leaving

- The objective of the tank heater are to:

- Keep the effluent T at a desired value Ts

- Keep the volume of the liquid at desired value Vs

- Control action is needed to keep T and V at the desired values.

- **Feedback control configuration**

- T is measured and compared with Ts

- Error $=$ Ts $-$ T is sent to a controller

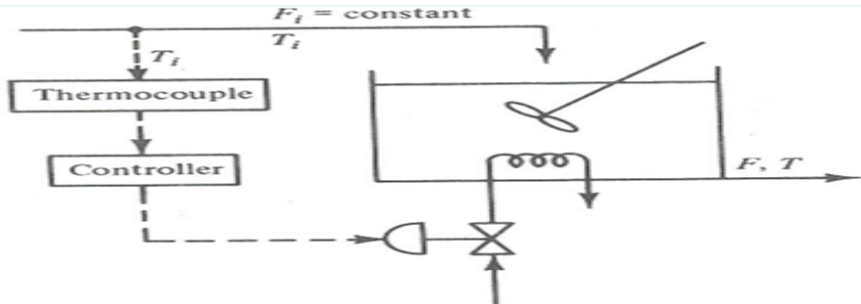- The controller takes a corrective action based on the error
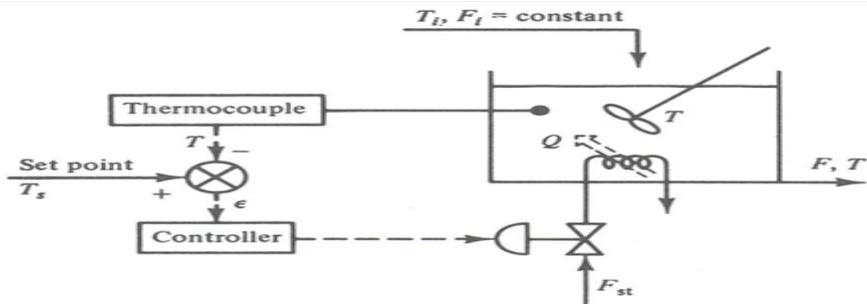
- h is controlled output

- F is manipulated variable

- Fi and Ti are disturbance inputs
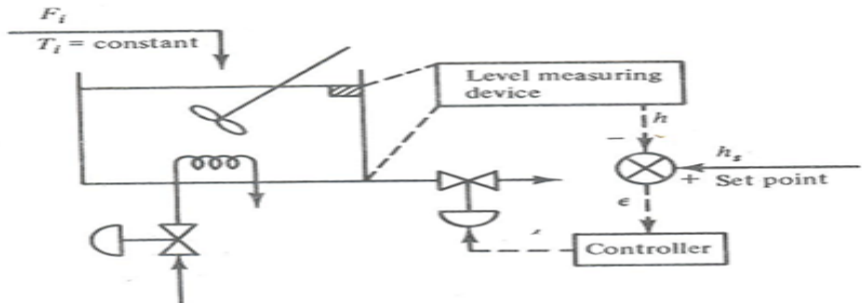
Feed-forward Control Configuration

Control types

- **1) MIMO (multiple input multiple output)**: a system having more than one manipulated variables and more than one output variables.

- **2) SISO (single input single output)**: a system with one manipulated and one controlled output variables.

- Criteria in selecting manipulated variables:
    - The choice of appropriate manipulated variables should affect the performance of control systems significantly.
    - In general the manipulated variables:
    - Should have direct and strong effect on the controlled variables
    - Be simple to adjust
    - Eg. Flow rates can be adjusted easily with a control valve

Instruments of a control system

The hardware elements involved in a process control system are the following:

- Chemical Process

- Sensors or the measuring instruments

- Transmission lines

- Transducers

- Transmitters

- The controller

- The final control element

1) Chemical Process: It represents the material equipment together with the physical or chemical operations that occur there.

2) Sensors or the measuring instruments: the instruments used to measure the variables (disturbances, controlled output or secondary output variables) and are the main sources of information about what is going on in the process.

- Characteristic examples are:
  - thermocouples or resistance thermometers: for measuring the temperature,
  - venture meters: for measuring the flow rate,
  - gas chromatographs: for measuring the composition of a stream, etc.

Factors affecting sensors selecting

- **Accuracy**: conforming with or closeness to the true value of the quantity being measured.

- **Precision**: the repeatability of the reading taken of the same value by the same instruments.

- **Resolution**: the smallest change in the input signal which can be detected by the instruments.

- **Sensitivity**: the measure of the change in output caused per unit change in input.

- **Cost effective**

3) Transmission lines: used to carry the measurement signal from the measuring device to the controller.

- Cables for electrical signals
- Tubes for pneumatic signals

4) Transducers: a device used to change one type of signals to another.

- It is a device that translates a mechanical signal into an electrical signal.
- Eg. I/P: current (electrical signal) to pressure (pneumatic signal).
- A converter is a device that converts one type of signal into another type of signal.
- For example, a converter may convert current into voltage

5) Transmitters: is a device that converts a reading from a sensor or transducer into a standard signal and transmits that signal to a monitor or controller.

- Transmitter types include:
- Pressure transmitters (PT)
- Flow transmitters(FT)
- Temperature transmitters(TT)
- Level transmitters (LT)

- An **indicator** is a human-readable device that displays information about the process.
- A **recorder** is a device that records the output of a measurement devices.

6) Controller: is a device that receives data from a measurement instrument, compares that data to a programmed set-point, and, if necessary, signals a control element to take corrective action.

- Controllers may perform complex mathematical functions to compare a set of data to set-point or they may perform simple addition or subtraction functions to make comparisons.

- All parameters are controlled by arrangement of various equipment like measuring devices, valves, controller.

- **Controller**: A device that outputs a signal to the process based on the magnitude of the error signal.

- **Error**: the difference between the measured variable and the set-point and can be either positive or negative.

- The objective of any control scheme is to minimize or eliminate error

7) The final control element: the hardware element that implements in real life the decision taken by the controller.

- It adjusts the value of the manipulated variable responses to the signal from the controller.

- The most frequently used in chemical process industries final control element is the control valve (pneumatic valve).

- The other final control elements are:

    - Relay switches (on-off)
    - Variables speed pump
    - Variables speed motors

Control Valves

- A control valve works on the principle of treating to adjust the manipulated variables.

- In automatic control installation, it normally consist of two parts

- The actuator, which translates the output signal from the controller into an action force.

- The body, which alters the flow rates of the manipulated variables to the required amount.

- There are three important aspects of a control valve:

    - Action of the valve (FO or FC)

    - The size of the valve (small or large)

    - The characteristics of the valve (linear or equal percentage)

1) Action of the valve: is the flow position of the valve when the signal from the controller fails.

In case of such a failure there are two most common actions:

- Completely open AC (Air to- close): FO (fail open)

- Completely close AO (air - open): FC (fail - close)

- Safety and economic analysis are the decisive factors in determining the action of the valve.

2) Size of the valve: valves are sized so that there is a balance b/n effective control action and the operating cost.

- Small valves are preferred from control point of view.

- Large valves are preferred from operating cost point of view.

3) Control valve characteristics: is the relationship b/n the step position of the valve and the flow rate of the manipulated variable.