Chapter 1: Introduction to Process Control

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Chapter Overview

This chapter consists of the following topics:

1. Process Dynamics and Control
2. Elements of Control System
3. Introduction to Process
   - Definition of Process
   - Process Variables

Chapter Overview

This chapter consists of the following topics:

4. A Illustrative Example – a Blending System
   - Blending System
   - Control Strategies for Blending System
5. Feedback (FB) and Feedforward (FF) Control
6. Control Elements
7. Block Diagram
8. Specific Objectives of Control
9. Summary

Learning Objectives

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

- Explain the importance of process control and process dynamics
- Determine important elements of the control system
- Explain the concepts relating to process and process variables
- Analyse the control strategies using blending system as an example

Learning Objectives

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

- Analyse feedback and feedforward control strategies
- List the four control elements
- Explain the use of block diagram
- List the specific objectives of control

Why Study Process Control?

- Due to performance requirements:
  - Stronger competition
  - Tougher environmental and safety regulations
  - Rapidly changing economic conditions
  - Complex and highly integrated process
- Due to increased emphasis on safe, efficient and high quality process, process control has become increasingly important
- Computer-based process control systems

Process Dynamics

- Refers to the unsteady-state (or transient) process behavior

- Transient operations occurs during:
  - Start-ups and shutdowns
  - Unusual process disturbances
  - Planned transitions from one product to another

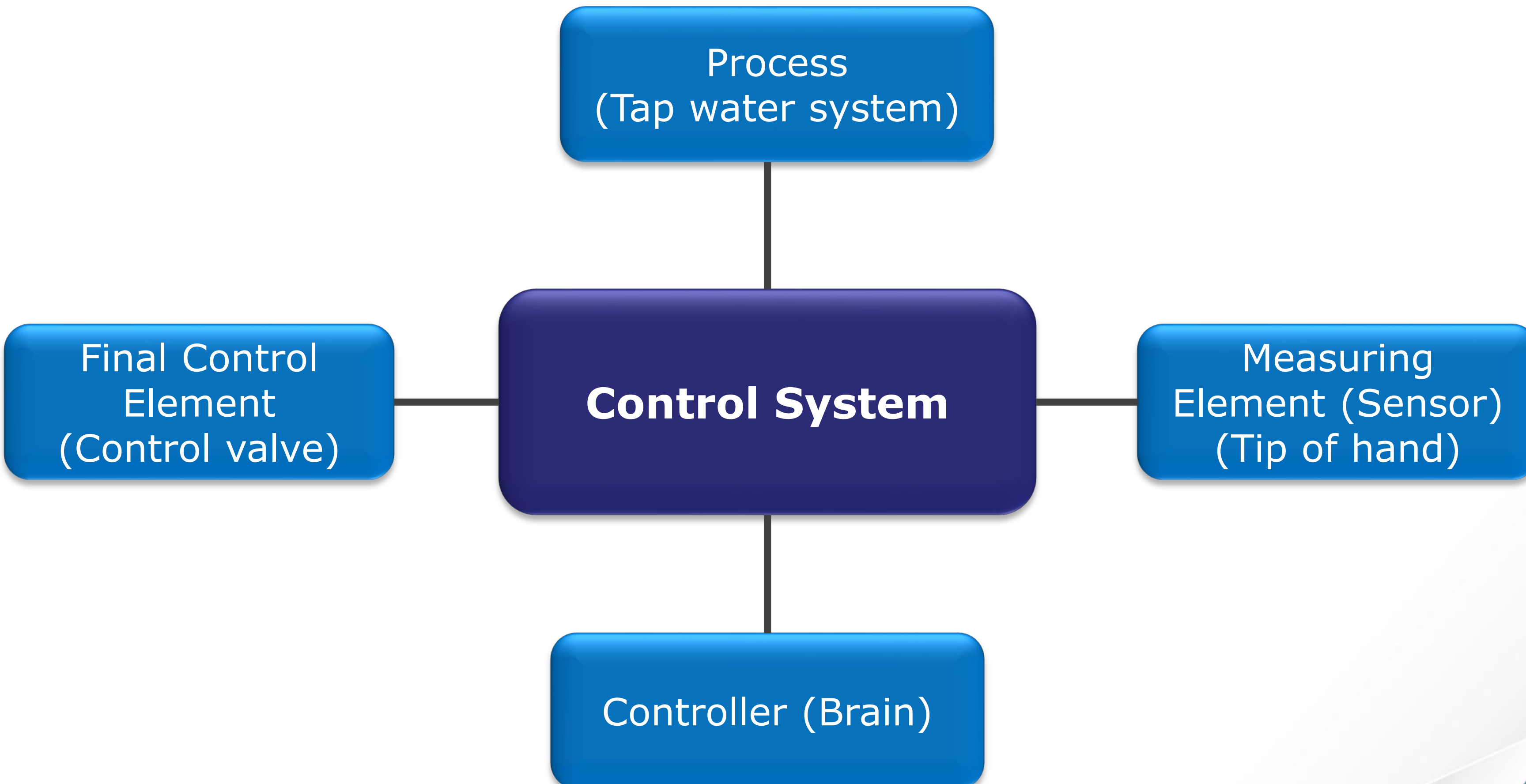
Process Control

- Process control maintains a process at the desired operating conditions, safely and efficiently while satisfying environmental and product quality specifications.
- In large-scale and integrated processing plants, thousands of process variables must be controlled.

Process Control

Example: The process of washing hands

Essential Elements of Control System

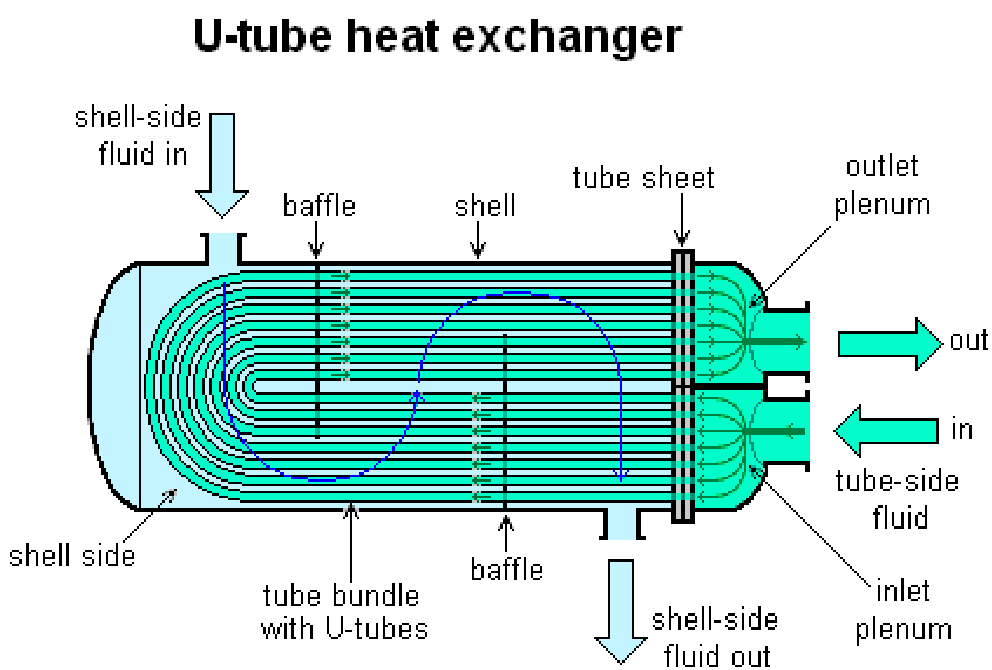


Control System

Control Loop

Process

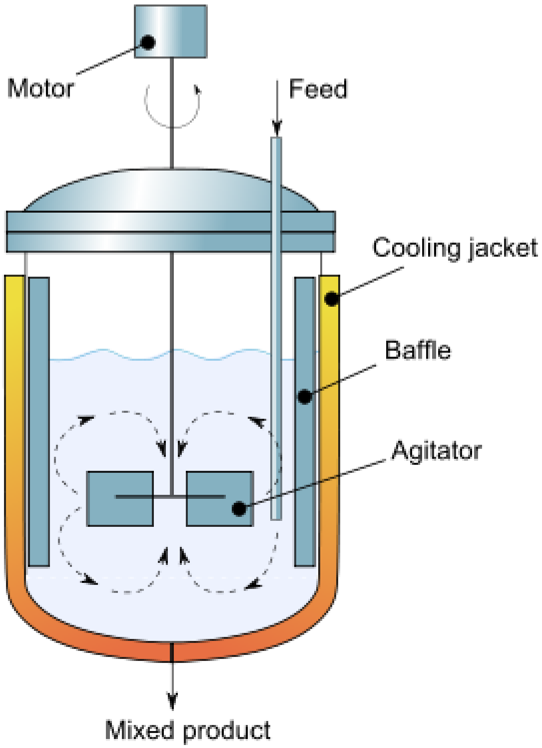
- What is a process?



Source: Shell and tube heat exchanger. (n.d.). Retrieved March 03, 2016, from https://en.wikipedia.org/wiki/Shell_and_tube_heat_exchanger

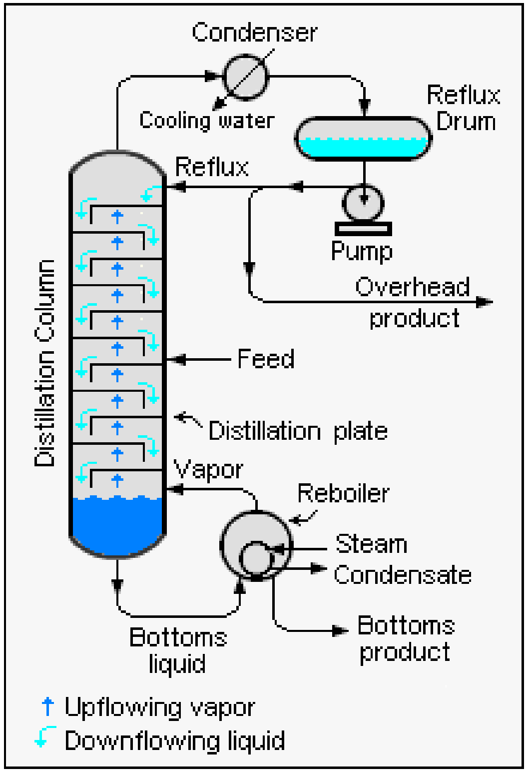
Process

- What is a process?



Continuous stirred-tank reactor

Source: Continuous stirred-tank reactor. (n.d.). Retrieved March 03, 2016, from https://en.wikipedia.org/wiki/Continuous_stirred-tank_reactor



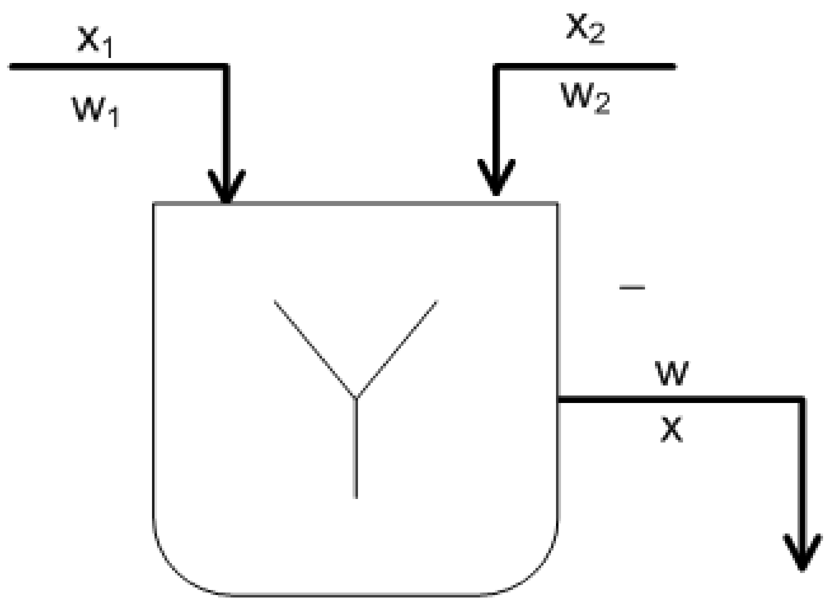
Fractionating column

Source: Fractionating column. (n.d.). Retrieved March 03, 2016, from https://en.wikipedia.org/wiki/Fractionating_column

Process Variables

- Controlled variables (CVs)
  - These are the variables that quantify the performance or quality of the final product, which are also called output variables. The desired value of the CV is referred to as its set point.
- Manipulated variables (MVs)
  - These input variables are adjusted dynamically to keep the controlled variables at their set-points.
- Disturbance variables (DVs)
  - These are called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points.

Illustrative Example: 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

Blending System

Assumptions:

1. w_1 is constant
2. x_2 = constant = 1 (stream 2 is pure A)
3. 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

Blending System

Design Question: What value of $\bar{w}_2$ is required to have $\bar{x} = x_{SP}$?

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 $\bar{w}_2$:

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

Blending System

- 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 $\bar{x}$ 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 $x_1 > \bar{x}_1$ and $w_2 = \overline{w}_2$, then $x > x_{SP}$.

Some Possible Control Strategies: Method 1

- Measure x and adjust w_2
  - Intuitively, if x is too high, we should reduce w_2
- Manual control vs automatic control
- Proportional feedback control law

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

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

For this system, is K_c Positive or Negative?

Method 1: Diagram

Some Possible Control Strategies: Method 2

- Measure x_1 and adjust w_2
- 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:

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

Method 2: Diagram

Feedforward Control

Some Possible Control Strategies

- Method 3
  - Measure x_1 and x, adjust w_2

- Method 4
  - Use a larger tank
  - If a larger tank is used, fluctuations in x_1 will tend to be damped out due to the larger capacitance of the tank contents
  - However, a larger tank means an increased capital cost

Classification of Process Control Strategies

Table 1.1. Control Strategies for the Blending System

Method	***Measured Variable***	***Manipulated Variable***	***Category***
1	x	w_2	**FeedBack (FB)**
2	x_1	w_2	**FeedForward (FF)**
3	x_1 **and** x	w_2	**FF/FB**
4	**-**	**-**	**Design change**

Feedback Control Strategy (FB)

- Distinguishing feature
  - Measure the controlled variable
  - Negative feedback (desirable) and positive feedback (Engineering vs social sciences)
- Advantages
  - Corrective action is taken regardless of the source of the disturbance
  - Reduces sensitivity of the controlled variable to disturbances and process change
- Disadvantages
  - No corrective action occurs until after the disturbance has upset the process, that is, until after x differs from x_{sp}

Feedforward Control Strategy (FF)

- Distinguishing feature
  - Disturbance variable is measured
- Advantages
  - Correct for disturbance before it upsets the process
- Disadvantages
  - Must be able to measure the disturbance
  - No corrective action for unmeasured disturbances
  - Process model is required

Control Elements

1. Process

- Model of the process (relates input with the output)
- Input variable (Manipulated or disturbance)
- Output variable (Controlled)
- Output variable to be at a desired value i.e., set point

Control Elements

2. Measuring Element (Sensor)

- Measures the controlled variable
- Thermocouple, gas chromatograph, etc.

3. Controller

- Converts the actual set point into an equivalent internal signal
- Calculates the error $e(t)$ by subtracting the measured value from the set point (desired value of CV)
- Controller output $p(t)$ is calculated from the proportional control law

4. Final Control Element

Block Diagram

- Physical connections between the components of the control system
- Flow of information within the control system
- Input and output signal for each component
- Allows visualisation of process behavior
- Includes one block for each element of the control loop
- Each block/ component contains a math model
- Open Loop vs Closed Loop block diagram

Specific Objectives of Control

- Increased product throughput
- Increased yield of higher valued products
- Decreased energy consumption
- Decreased pollution
- Decreased off-spec product
- Increased safety
- Extended life of equipment
- Improved operability
- Decreased production labor

Summary

Below are the key points we have covered in this chapter:

- Basic control terminologies such as input and output variables.
- Various control strategies and objectives of control reveal the emphasis placed on safe, efficient plant operation.

Suggested Reading: Chapter 1 of SEMD (Seborg, Edgar, Mellichamp and Doyle *Third Edition*).

Chapter 1: Introduction to Process Control

The End.