Chapter 4
Lecture # 1-2

- **Overview of Chapter 4.**
- **Operating Pressure and Temperature.**
- **Reasons to Operate Outside the Normal Operating Conditions.**

Chapter 4 Overview

Title: Understanding Process Conditions

Objectives:

1) Analyze reasons for selecting specific conditions (T, P, and X).

2) Analyze process conditions that require special consideration.

Operating Pressure and Temperature

It is easier to adjust T and/or P of a stream than to change composition.

- The following conditions do not cause severe difficulties:
  - Temperatures between 40 - 260 degrees C
  - Pressures between 1 - 10 bar
- Conditions outside the above favored temperature and pressure ranges are identified as “conditions of special concern”

Operating Pressure and Temperature

Above 10 bar

- Thicker walled expensive equipment
- Safety issue

1- 10 bar

- Favorable condition

Below 1 bar

- Large equipment
- Special construction techniques

Increase in cost

Operating Pressure and Temperature

- Elevated
- temperature

→

Drop in physical strength of construction materials

→

Replacement By more costly materials

Operating Pressure and Temperature

Example 4.1

The maximum allowable tensile strength for a typical carbon steel and stainless steel, at ambient temperature, 400°C, and 550°C is provided below (from Walas [1]).

	Tensile Strength of Material at Temperature Indicated (bar)		
Temperature	**Ambient**	**400°C**	**550°C**
Carbon Steel (grade 70)	1190	970	170
Stainless Steel (Type 302)	1290	1290	430

Determine the fractional decrease in the maximum allowable tensile strength (relative to the strength at ambient conditions) for the temperature intervals: (a) ambient to 400°C and (b) 400°C to 550°C.

Operating Pressure and Temperature

a. Interval: ambient to 400°C:

Carbon Steel: (1190-970)/1190 = 0.18

Stainless Steel: (1290-1290)/1290 = 0.0

b. Interval: 400°C to 550°C:

Carbon Steel: (970-170)/1190 = 0.67

Stainless Steel: (1290-430)/1290 = 0.67

Operating Pressure and Temperature

Below 40 C	40 - 260 C	Above 260 C
Require refrigeration	Ok	Require special heaters

Operating Pressure and Temperature

High T

High Pressure Steam (250 to 265 Degrees C).

Above 260 Degrees C (Fired Heater).

Operating Pressure and Temperature

Low T

Cooling Water (40 Degrees C).

Below 40 Degrees C (Refrigerant).

Operating Costs (Table 6.3)

- Cooling Water $0.16/ GJ
- Refrigerated Water $20.60/ GJ

Reasons to Operate Outside the Normal Operating Conditions

1. Favorable equilibrium conversion
2. Increase in reaction rates

$$k_{reaction} = k_0 e^{-\frac{E_{act}}{RT}}$$

3. Maintain a gas phase
4. Improve selectivity

Reasons to Operate Outside the Normal Operating Conditions

Table 4.1 Possible Reasons for Operating Reactors and Separators Outside the Temperature Ranges of Special Concern

Stream Condition	Process Justification for Operating at This Condition	Penalty for Operating at This Condition
High Temperature [T > 250°C]	**REACTORS** (i) Favorable equilibrium conversion for endothermic reactions (ii) Increase reaction rates (iii) Maintain a gas phase (iv) Improve selectivity (v) (vi) **SEPARATORS** (i) Obtain a gas phase required for vapor-liquid equilibrium (ii) (iii)	i) Use of special process heaters (ii) T > 400°C requires special materials of construction (iii) (iv) (v)

Reasons to Operate Outside the Normal Operating Conditions

Low Temperature [T < 40°C]

REACTORS

(i) Favorable equilibrium conversion for exothermic reactions
(ii) Temperature sensitive materials
(iii) Improve selectivity
(iv) Maintain a liquid phase
(v)
(vi)

(i) Uses expensive refrigerant
(ii) May require special materials of construction for very low temperatures
(iii)
(iv)
(v)

SEPARATORS

(i) Obtain a liquid phase required for vapor-liquid or liquid-liquid equilibrium
(ii) Obtain a solid phase for crystal-lization
(iii) Temperature sensitive materials
(iv)
(v)

Reasons to Operate Outside the Normal Operating Conditions

Table 4.2 Possible Reasons for Operating Reactors and Separators Outside the Pressure Range of Special Concern

Stream Condition	Process Justification for Operating at This Condition	Penalty for Operating at This Condition
High Pressure (P > 10 bar)	**REACTORS** (i) Favorable equilibrium conversion (ii) Increase reaction rates for gas phase reactions (due to higher concentration) (iii) Maintain a liquid phase (iv) (v)	(i) Requires thicker-walled equipment (ii) Requires expensive compressors if gas streams must be compressed (iii) (iv) (v)
	SEPARATORS (i) Obtain a liquid phase for vapor-liquid or liquid-liquid equilibrium (ii) (iii)	

Reasons to Operate Outside the Normal Operating Conditions

Low Pressure ($P < 1$ bar)	**REACTORS** (i) Favorable equilibrium conversion (ii) Maintain a gas phase (iii) (iv)	(i) Requires large equipment (ii) Special design for vacuum operation (iii) Air leaks into equipment that may be dangerous and expensive to prevent (iv) (v) (vi)
	SEPARATORS (i) Obtain a gas phase for vapor-liquid equilibrium (ii) Temperature-sensitive materials (iii) (iv)	

Reasons to Operate Outside the Normal Operating Conditions

Table 4.3 Possible Reasons for Nonstoichiometric Reactor Feed Compositions of Special Concern

Stream Condition	Process Justification for Operating at This Condition	Penalty for Operating at This Condition
Inert Material in Feed to Reactor	(i) Acts as a diluent to control the rate of reaction and/or to ensure that the reaction mixture is outside the explosive limits (exothermic reactions) (ii) Inhibits unwanted side reactions (iii) (iv)	(i) Causes reactor and downstream equipment to be larger since inert takes up space (ii) Requires separation equipment to remove inert material (iii) May cause side reactions (material is no longer inert) (iv) Decreases equilibrium conversion (v) (vi)
Excess Reactant	(i) Increases the equilibrium conversion of the limiting reactant. (ii) Inhibits unwanted side reactions. (iii) (iv)	(i) Requires separation equipment to remove excess reactant (ii) Requires recycle (iii) Added feed material costs (due to losses in separation and/or no recycle) (iv) (v)

Reasons to Operate Outside the Normal Operating Conditions

Product present in feed to reactor	(i) Product cannot easily be separated from recycled feed material. (ii) Recycled product retards the formation of unwanted by-products formed from side reactions. (iii) Product acts as a diluent to control the rate of reaction and/or to ensure that the reaction mixture is outside the explosive limits, for exothermic reactions. (iv) (v)	(i) Causes reactor and downstream equipment to be larger (ii) Requires larger recycle loop (iii) Decreases equilibrium conversion (iv) (v)