458.401 Process & Product Design

05

Understanding Process Conditions

Jong Min Lee
School of Chemical and Biological Engineering
Seoul National University

Heuristics

Temperature

< 40 °C	> 250 °C	> 400 °C
Require refrigeration	Require fired heater	Special M.O.C.

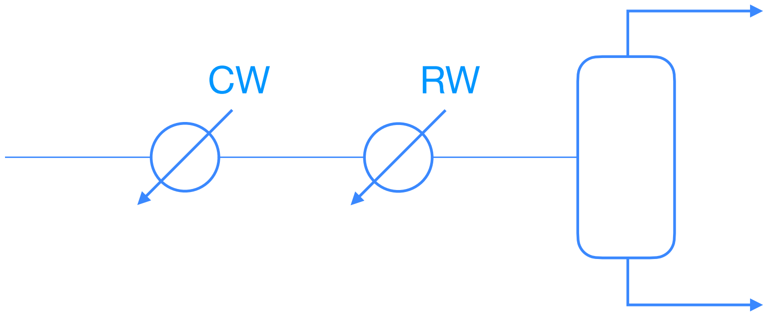
Pressure

< 1 atm	> 10 atm
Need vacuum	Thick walls - $

Temperature

T < 40 °C - Refrigeration

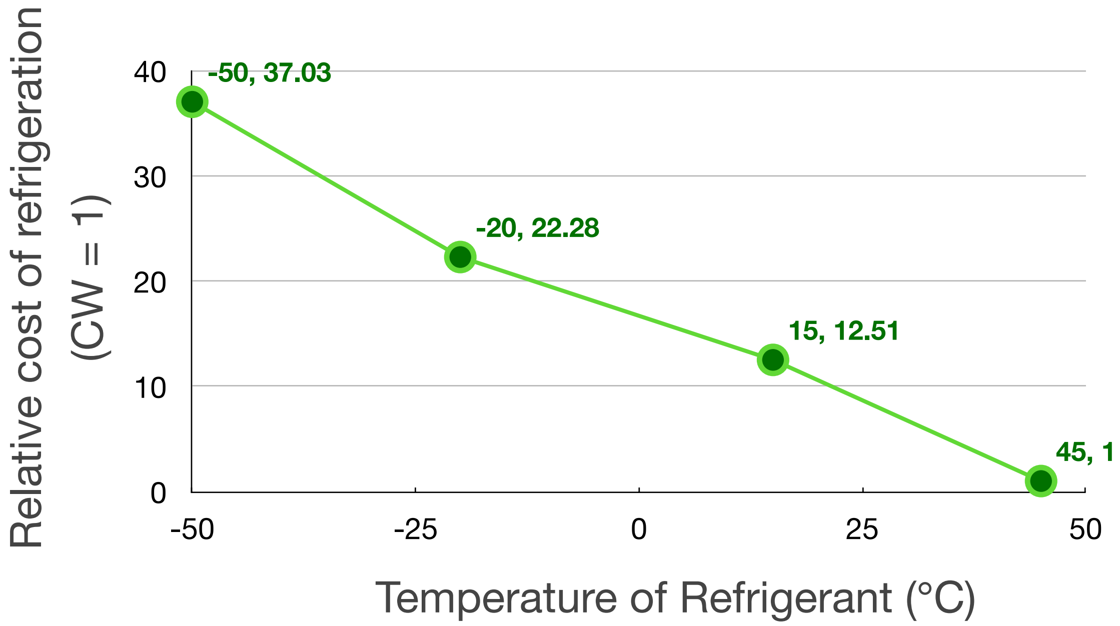
Use as much cooling water as possible



Operating costs (Table 8.3)

Cooling Water (30 - 40°C)	$0.378/GJ
Refrigerated Water (5 - 15°C)	$4.77/GJ

Temperature



Temperature

- T > 250 °C - hp steam @ 260 °C (600 psig)
  - Need a molten salt / Dowtherm loop
  - Fired heaters are very expensive
- Compare - Vaporizer

$$Q = 10,000 \text{ kW}$$

$$U = 1,000 \text{ W/m}^2\text{K}$$

$$\Delta T = 30 \text{ °C}$$

$$A = \frac{10 \times 10^6}{10^3 \times 30} = 333 \text{ m}^2$$

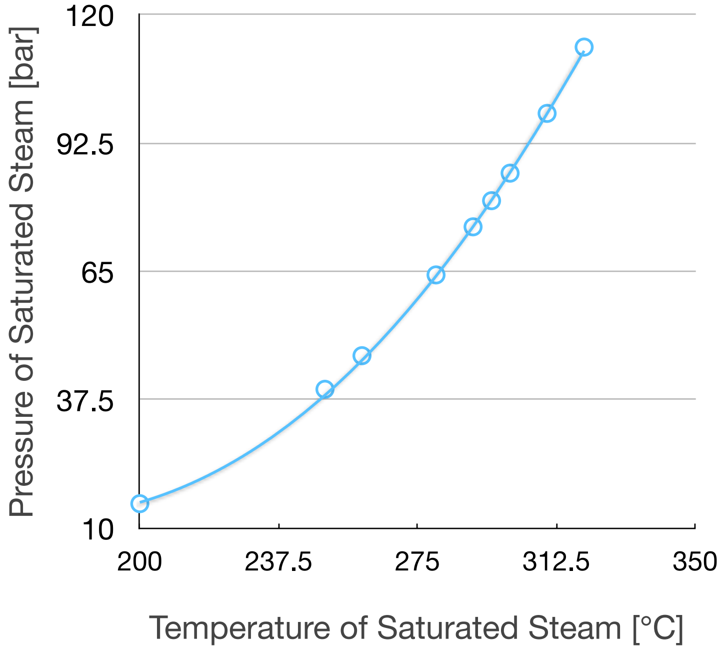
- Typical heat transfer rates in industrial heat exchangers vary from 10 kW to 100,000 kW
- Typical U-values are 200 Btu/hr ft^2 °F (1136 W/m^2 K) for rebillers and 90 Btu/hr ft^2 °F (511 W/m^2 K) for air coolers.
- The area of industrial heat exchangers is typically from 1m^2 to 3000 m^2

Temperature

- C_{BM} (Bare Module Cost)
  - The sum of the direct and indirect costs associated with equipment purchase and installation
  - Heat Exchanger = $ 1.70 x 10^5
  - Fired Heater = $ 1.81 x 10^6
- T > 400°C
  - M.O.C. is very important

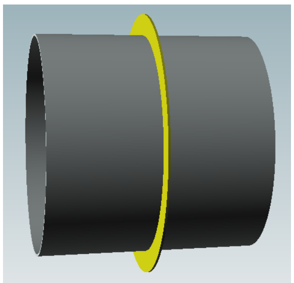
Why not use high-pressure steam?

Psat [bar]	Tsat [°C]
15.2	200
39.7	250
46.9	260
64.2	280
86.0	300
74.5	290
80.1	295
98.8	310
113.0	320



Pressure

- Vacuum
  - Slightly higher cost due to stiffening rings
  - Large equipment
  - Air leaks
- High Pressure
  - Thick walls ($)
  - H_2 embrittlement
  - Safety



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Minimum Wall Thickness

$$t = \frac{P \cdot R}{S \cdot E - 0.6P} + CA$$

t: wall thickness [m]

P: design pressure [bar]

R: vessel radius [m]

S: design stress (Max Allowable Working Pressure) [bar]
This is a function of material and temperature

E: Weld efficiency (~0.9)

CA: Corrosion allowance (0.00315 to 0.00625 m)

Minimum Wall Thickness

Look at 36 inch diameter vessel with a CA of 1/4 in (= 0.00635 m) made of CS with S = 13,700 psi (= 944 bar)

P [bar]	t [m]	t/CA
1	0.0069	1.09
4	0.0085	1.34
10	0.0118	1.86

As P > 10, then t > 2CA

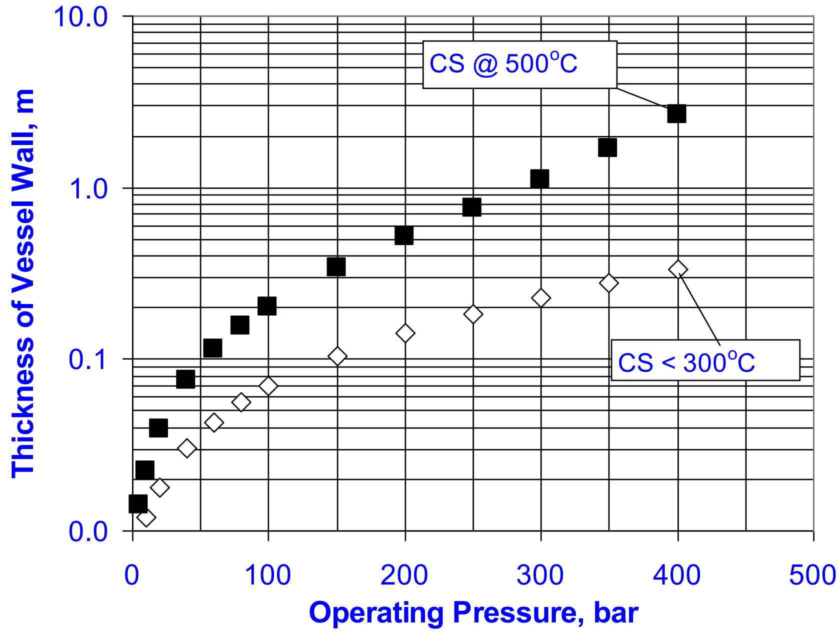
What about S vs. T?

- Look at several steels in graph
- For CS, S↓ as T > 400°C
- Must use Stainless Steel and $↑
- For a given pressure
  - t ↑ as T ↑

Figure 5.5

Material of Construction

1m diameter vessel made of SA285 - Grade A Carbon Steel



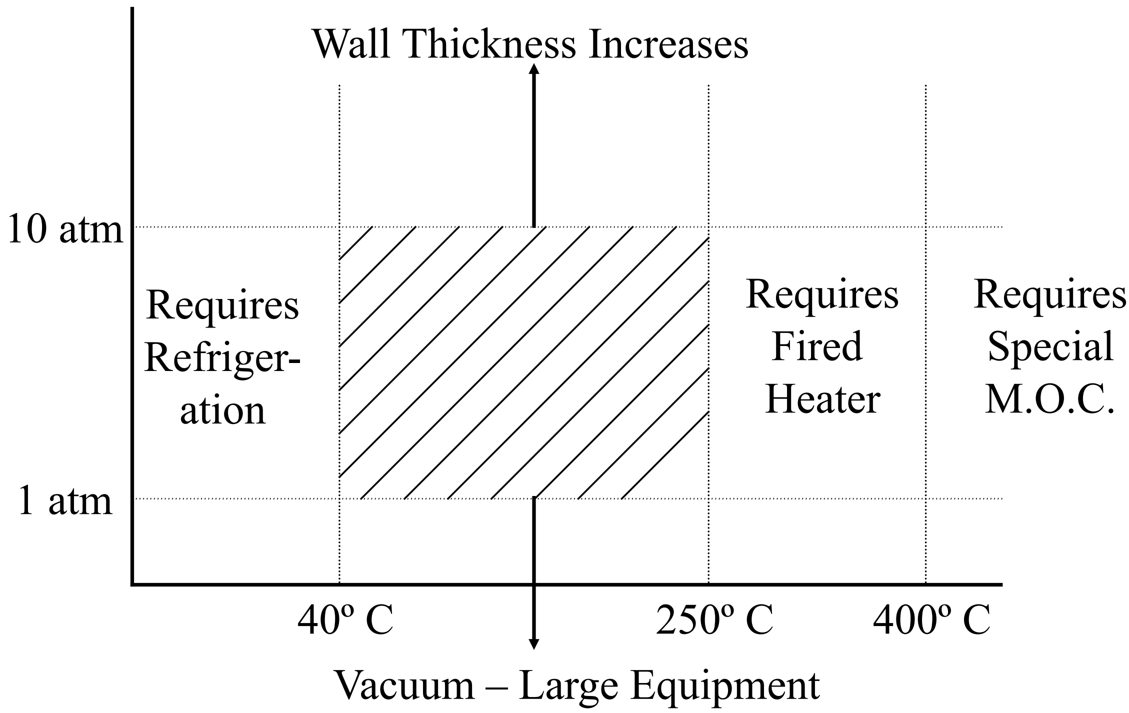
Material of Construction

- Carbon Steel
  - Cheap
- Stainless Steel
  - Expensive
  - Better chemical / thermal resistance
- What about T = 700 - 900°C?
  - Insulate inside of pipe
  - Metal-refraction lining

Conclusions

- T < 40°C - Refrigeration
- T > 250°C - Fired heater or furnace
- T > 400°C - M.O.C. issues
- P < 1 atm - Vacuum and large equipment
- P > 10 atm - Cost ↑

Operating Condition



Do we ever operate outside these limits?

- Tables 6.1 - 6.3
  - Reactors and Separators
- Table 6.4
  - Other equipment

Example 1 - Acrylic Acid

Why does T-1005 operate with the top pressure at 0.07 bar?

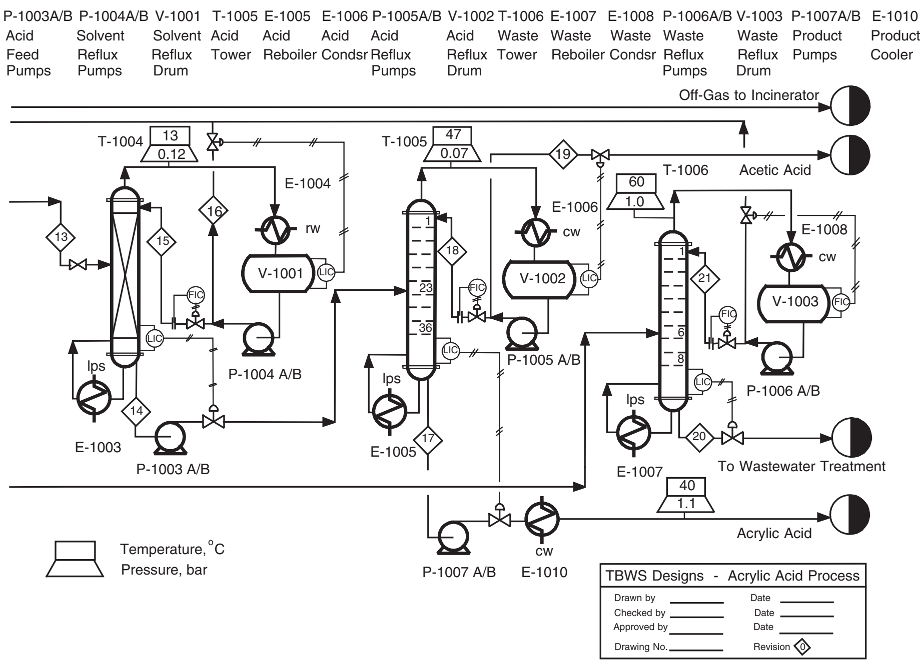


Figure B.9.1 *(Continued)*

Solution-01

Feed

86.6 kmol/h Acrylic Acid: n.b.p. = 140 °C

6.1 kmol/h Acetic Acid: n.b.p. = 118 °C

Table 6.2 - Reasons for using P < 1 atm

1. Obtain a __________ for VLE
2. __________ sensitive materials

Example-02

Typical depropanizer operates at 220 psig (16 bar) why?

Solution-02

Reasons for using P > 10 bar:

1. Obtain a __________ for VLE