Chapter 9
Lecture # 1-2

- **Tables of Technical Heuristics and Guidelines**

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Table 9.2(a) Physical Property Heuristics

	Units	Liquids		Liquids	Gases	Gases	Gases
		Water		Organic Material	Steam	Air	Organic Material
Heat Capacity	kJ/kg°C	4.2		1.0–2.5	2.0	1.0	2.0–4.0
Density	kg/m^3	1000		700–1500		1.29@STP	
Latent heat	kJ/kg	1200–2100		200–1000			
Thermal conductivity	W/m°C	0.55–0.70		0.10–0.20	0.025–0.07	0.025–0.05	0.02–0.06
Viscosity	kg/m s	0°C	1.8×10^{-3}	Wide Range	$10–30 \times 10^{-6}$	$20–50 \times 10^{-6}$	$10–30 \times 10^{-6}$
		50°C	5.7×10^{-4}				
		100°C	2.8×10^{-4}				
		200°C	1.4×10^{-4}				
Prandtl No.		1–15		10–1000	1.0	0.7	0.7–0.8

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Table 9.2(b) Typical Physical Property Variations with Temperature and Pressure

	Liquids	Liquids	Gases	Gases
Property	Temperature	Pressure	Temperature	Pressure
Density	$\rho_l \propto (T_c - T)^{0.3}$	Negligible	$\rho_g = MW.P/ZRT$	$\rho_g = MW.P/ZRT$
Viscosity	$\mu_l = Ae^{B/T}$	Negligible	$\mu_g \propto \dfrac{T^{1.5}}{(T + 1.47T_b)}$	Significant only for $P > 10$ bar
Vapor Pressure	$P^* = ae^{b/(T+c)}$	—	—	—

T is temperature (K), T_c is the critical Temperature (K), T_b is the normal boiling point (K), MW is molecular weight, P is pressure, Z is compressibility, R is the gas constant, and P^* is the vapor pressure.

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Table 9.3 Capacities of Process Units in Common Usage[a]

Process Unit	Capacity Unit	Max. Value	Min. Value	Comment
Horizontal vessel	Pressure (bar)	400	Vacuum	*L/D* typically 2–5, see Table 9.6
	Temper. (°C)	400[b]	−200	
	Height (m)	10	2	
	Diameter (m)	2	0.3	
	L/D	5	2	
Vertical vessel	Pressure (bar)	400	400	*L/D* typically 2–5, see Table 9.6.
	Temper. (°C)	400[b]	−200	
	Height (m)	10	2	
	Diameter (m)	2	0.3	
	L/D	5	2	
Towers	Pressure (bar)	400	Vacuum	Normal Limits
	Temper. (°C)	400[b]	−200	Diameter — *L/D*
	Height (m)	50	2	0.5 — 3.0–40[c]
	Diameter (m)	4	0.3	1.0 — 2.5–30[c]
	L/D	30	2	2.0 — 1.6–23[c]
				4.0 — 1.8–13[c]
Pumps				
Reciprocating	Power[d] (kW)	250	< 0.1	
	Pressure (bar)	1000		
Rotary and positive Displacement	Power[d] (kW)	150	< 0.1	
	Pressure (bar)	300		
Centrifugal	Power[d] (kW)	250		< 0.1
	Pressure (bar)	300		

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Table 9.4 Effect of Typical Materials of Construction on Product Color, Corrosion[a], Abrasion, and Catalytic Effects

Metals		
Material	*Advantages*	*Disadvantages*
Carbon steel	Low cost, readily available, resists abrasion, standard fabrication, resists alkali	Poor resistance to acids and strong alkali, often causes discoloration and contamination
Stainless steel	Resists most acids, reduces discoloration, available with a variety of alloys, abrasion less than mild steel	Not resistant to chlorides, more expensive, fabrication more difficult, alloy materials may have catalytic effects
Monel-Nickel	Little discoloration, contamination, resistant to chlorides	Not resistant to oxidizing environments, expensive
Hasteloy	Improved over Monel-Nickel	More expensive than Monel-Nickel
Other exotic metals	Improves specific properties	Can be very high cost

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Table 9.6 Heuristics for Process Vessels (Drums)

1. Drums are relatively small vessels that provide surge capacity or separation of entrained phases.
2. Liquid drums are usually horizontal.
3. Gas/liquid phase separators are usually vertical.
4. Optimum length/diameter = 3, but the range 2.5 to 5 is common.
5. Holdup time is 5 min for half-full reflux drums and gas/liquid separators, 5–10 min for a product feeding another tower.
6. In drums feeding a furnace, 30 min for half-full drum is allowed.
7. Knockout drums placed ahead of compressors should hold no less than 10 times the liquid volume passing per minute.
8. Liquid/liquid separations are designed for settling velocity of 0.085–0.127 cm/s (2–3 in/min)

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Example 9.2

Refer to the information given in Chapter 1 for the toluene hydrodealkylation process, namely, Figure 1.7 and Tables 1.5 and 1.7. Using the information provided in the tables in this chapter, estimate the size of the equipment and other operating parameters for the following units:

a. V-102
b. E-105
c. P-101
d. C-101
e. T-101
f. H-101

Compare your findings with the information given in Chapter 1.

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a. V-102—High-Pressure Phase Separator

From Table 9.6, we use the following heuristics

Rule 3 → Vertical Vessel
Rule 4 → L/D between 2.5 and 5 with optimum at 3.0
Rule 5 → liquid hold-up time is 5 min based on 1/2 volume of vessel
Rule 9 → Gas velocity u is given by

$$u = k\sqrt{\frac{\rho_l}{\rho_v} - 1}\ \text{m/s}$$

where $k = 0.0305$ for vessels without mesh entrainers

Rule 12 → Good performance obtained at 30–100% of u from Rule 9; typical value is 75%

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From Table 1.5, we have
Vapor flow = Stream 8 = 9200 kg/h, P = 23.9 bar, T = 38°C
Liquid flow = Stream 17 + 18 = 11570 kg/h, P = 2.8 bar, T = 38°C
$\rho_v = 8\ \text{kg/m}^3$ and $\rho_l = 850\ \text{kg/m}^3$ (estimated from Table 1.7)

From Rule 9, we get $u = 0.0305[850/8 - 1]^{0.5} = 0.313$ m/s
Use $u_{act} = (0.75)(0.313) = 0.23$ m/s
Now mass flowrate of vapor = $u\rho_v\pi D^2/4 = 9200/3600 = 2.56$ kg/s
Solving for D, we get $D = 1.33$ m

From Rule 5, we have volume of liquid = $0.5\ L\pi D^2/4 = 0.726L\ \text{m}^3$
5 minutes of liquid flow = $(5)(60)(11{,}570)/850/3600 = 1.13\ \text{m}^3$
Equating the two results above, we get $L = 1.56$ m

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From Rule 4, we have L/D should be in range 2.5 to 5. For our case $L/D = 1.56/1.33 = 1.17$

Because this is out of range, we should change to $L = 2.5D = 3.3$ m

Heuristics from Table 9.6 suggest that V-102 should be a vertical vessel with $D = 1.33$ m, $L = 3.3$ m

From Table 1.7, we see that the actual V-102 is vertical vessel with $D = 1.1$ m, $L = 3.5$ m