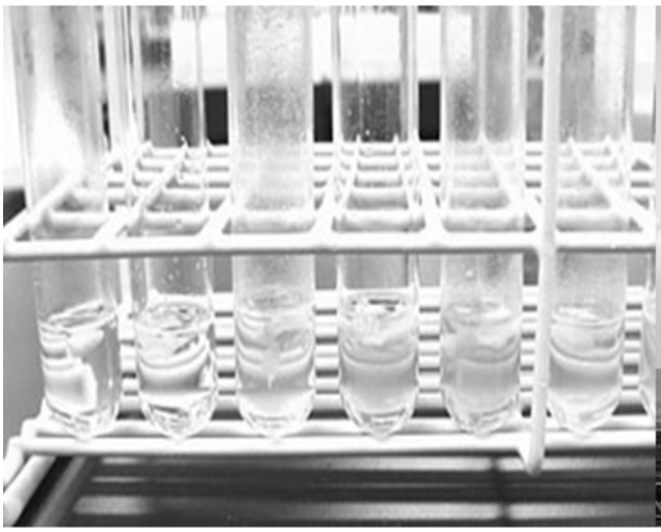
Introduction to Rules of Thumb (4)
- Pressure Vessels -



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Introduction

- The design of a chemical plant must be carried out strictly on the basis of theory and data, but in the initial examination stage where F/S and the process purposes are to be determined, promptness is required rather than accuracy, and in this regard simple rough calculation methods and common sense design values are very effective.
- Such methods and design values are given names such as “Conceptual Process Design” or “Rules of Thumb”. They are kept by individuals or at a company level and are often published as documents.
- In this report, based on “Rules of Thumb: Selecting and Designing Equipment” by S. M. Walas (Chemical Engineering, March 16, 1987), the introduction of Rules of Thumb is compared with the contents described in handbooks and the like. (Document no. 4: Pressure Vessels).

1. Reactors

Introduction to Rules of Thumb

① Laboratory and Pilot Plant Services
- Reaction rate: established in the lab
- Residence time and space velocity: established in the pilot plant
- Product quality: confirmed by the pilot plant

② Catalyst Diameter and Reactor Type
- Catalyst particle size
  - ≈ 0.1 mm ... Fluidized bed
  - ≈ 1 mm ... Suspended bed
  - ≈ 2 to 5 mm ... Fixed bed

③ Shape of Stirred Tank Reactor
- It is most common to make the liquid depth and the tank diameter the same
- In the case of a high pressure vessel, it is more economical to reduce the tank diameter (reduce the plate thickness)

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1. Reactors

Introduction to Rules of Thumb

④ Stirring Power
- For a homogeneous reaction: 0.5 to 1.5 [hp/1000 gal] (= 0.1 to 0.3 [kW/m^3])
- When it is necessary to consider heat transfer: Three times the above power.

⑤ CSTR
- 5 to 10 times the average residence time is required for the mixing condition to be completely uniform.
- Suitable for liquid phase reactions or slurry reactions with relatively slow reaction rates.
- 4 to 5 stages are most economical for multi-stage CSTR.

⑥ Batch Reaction
- Suitable for the following conditions.
  - Small product volumes
  - Long reaction times
  - When a fine control of the feed rate and temperature are required

Solutions for R&D to Design

1. Reactors

Introduction to Rules of Thumb

⑦ Tubular Reactor

- Suitable for short reaction times (of the order of seconds or minutes), high product rates, or very high heats of reaction.
- For temperature control, a jacketed tubular reactor or a multi-tubular reactor is used.
- When the reaction rate is 95% or less than the equilibrium value, the reaction performance of a 5-stage CSTR and the reaction performance of a tubular reactor are the same.

⑧ Fixed Bed Catalytic Reactor

- Residence time distribution is equivalent to 4 to 5 CSTR stages.

2. Drums

Introduction to Rules of Thumb

① Shape

- There are many horizontal drums for liquid.
- Vapor-liquid separation drums are of the vertical type.
- As a standard: Length (height) / Diameter = 3, generally this ratio is from 2.5 to 5.0.

② Holdup

- Reflux drum: 1/2 of drum volume and 5 minutes residence time
- Liquid feed drum (in process): Residence time of 5 to 10 minutes
- Feed drum to furnace: 1/2 of drum volume and 30 minutes residence time
- Knockout drum at compressor inlet: More than 10 times the gas flow rate in [m^3/min]

③ Separation Drums

- Liquid-liquid separation: Designed as separation speed 2 to 3 [in/min] (50 to 75 [mm/min])
- Vapor-liquid separation: Gas velocity V [ft/s] is designed based on the following calculated value:

$$V = k((\rho_L / \rho_V) - 1)^{1/2} \qquad \rho_L, \rho_V: \text{liquid, vapor density [lb/ft}^3\text{]}$$

$k = 0.35$ (without mesh demister), 0.1 (with mesh demister)

2. Drums

Introduction to Rules of Thumb

③ Separation Drums (Continued)

- A mesh pad of 4 to 12 inches (standard 6 inches) can prevent 99% of entrainment.
- If the mesh pad is placed vertically, k in the equation shown on the previous page is the value multiplied by 2/3.
- The gas velocity V is most commonly 75% of the calculated value on the previous page, but designing in the range of 30 to 100% will not cause performance problems.
- A space of 6 to 18 inches (standard 12 inches) should be provided at the top of the mesh pad.

④ Cyclone

- In general, it is designed so that 95% of particles having a particle size of 5 [μm] can be separated. However, it is usually sufficient if droplets of 50 [μm] or more can be separated.

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2. Drums

[Reference] Horizontal Drum ("Kagaku Souchi Binran", *In Japanese*: "Chemical Equipment Handbook" Revised 2nd ed., p. 439)

Cylindrical Tank

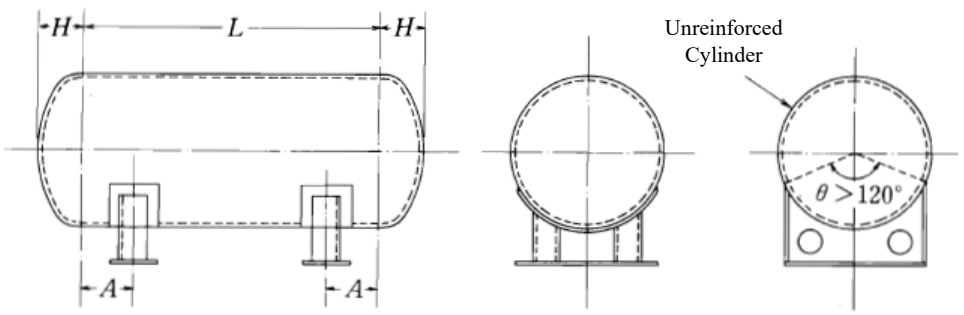

Fig. 11.32 Horizontal Cylinder

2. Drums

[Reference] Horizontal Drum ("Kagaku Souchi Binran", *In Japanese*: "Chemical Equipment Handbook" Revised 2nd ed., p. 431)

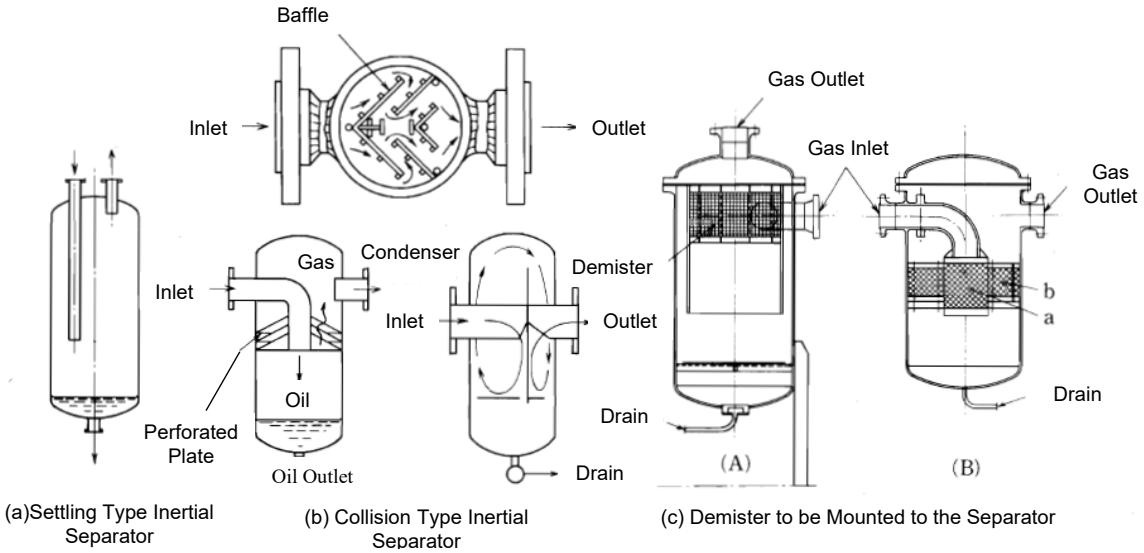

Figure 11.16 Vapor-Liquid Separators

3. Pressure Vessels

Introduction to Rules of Thumb

① Design Temperature

- When the process temperature is -20 to 650 [˚F] (= -29 to 343 [˚C]), the operating temperature is + 50 [˚F] (= 28 [˚C]).
- When the process temperature is out of the above range, increase the margin.

② Design Pressure

- Use 110% of the maximum operating pressure, or the maximum operating pressure +10 to 25 [psi] (= 0.7 to 1.8 [kg/cm^2]), whichever is larger.
- The maximum operating pressure is the normal operating pressure + 25 [psi] (= 1.8 [kg/cm^2]).
- When the operating pressure is 0 to 10 [psig] (= 0 to 0.7 [kg/cm^{2}G]) and the operating temperature is 600 to 1000 [˚F] (= 315 to 538 [˚C]), the design pressure is 40 [psig] (= 2.8 [kg/cm^{2}G]).
- When the operating pressure is negative, the design pressure is 15 [psig] (= 1.1 kg/cm^{2}G) and full vacuum.

3. Pressure Vessels

[Reference] Examples of Design Pressures and Design Temperatures ("Kagaku Kougaku Binran", *In Japanese*: "Chemical Engineering Handbook", Revised 7th ed., p. 929)

Table 16.4 Examples of Design Pressures and Design Temperatures

Design Pressure	Cylindrical Tank, Heat Exchanger	Maximum operating pressure 0 to 1.0 MPaG: Maximum operating pressure + 0.1 MPaG Maximum operating pressure of 1.0 MPa or more: Maximum operating pressure x 1.1 MPaG Maximum operating pressure of less than 0 MPaG: -0.1 MPaG
	Atmospheric Storage Tank	When the specific gravity of the contents is smaller than water: full water condition When the specific gravity of the contents is greater than water: full liquid condition
	Equipment and Piping for Centrifugal Pump Discharge	Maximum operating pressure of machinery on suction side + maximum liquid head on suction side + maximum differential pressure of pump
Design Temperature	Cylindrical Tank, Heat Exchanger, Storage Tank	<Maximum Design Temperature> Maximum design temperature of less than 50°C: 60°C Maximum design temperature from 50°C to 350°C: Maximum operating temperature + 10°C Maximum design temperature from 350°C to 800°C: Maximum operating temperature + 20 °C Maximum design temperature above 800°C: Maximum operating temperature + 30°C <Minimum Design Temperature> For a minimum outside temperature greater than the minimum operating temperature: minimum operating temperature (However, use the minimum outside temperature if the wall temperature is outside air) For a minimum outside air temperature smaller than the minimum operating temperature For a pressurized vessel: minimum outside air temperature For normal pressure: minimum operating temperature

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3. Pressure Vessels

Introduction to Rules of Thumb

③ Minimum Thickness

- ID 42 [in] (= 1070 [mm]) or less: 0.25 [in] (= 6.4 [mm])
- Inner diameter 42 to 60 [in] (= 1070 to 1520 [mm]): 0.32 [in] (= 8.1 [mm])
- Inner diameter 60 [in] (= 1520 [mm]) or more: 0.38 [in] (= 9.7 [mm])

④ Allowance for Corrosion

- Corrosive fluid: 0.35 [in] (= 8.9 [mm])
- Non-corrosive fluid: 0.15 [in] (= 3.8 [mm])
- Steam drum, air receiver: 0.06 [in] (= 0.7 [mm])

⑤ Allowable Stress

- Allowable stress used for design is 1/4 of the tensile strength of the material.
- Be careful because the allowable stress is strongly temperature dependent.

Solutions for R&D to Design

4. Storage Tanks

Introduction to Rules of Thumb

① Shape

- 1000 [gal] (= 3.8 [m^3]) or less: vertical type with legs is common
- 1000 to 10000 [gal] (= 3.8 to 38 [m^3]): horizontal type (concrete foundation) is common
- 10000 [gal] (= 38 [m^3]) or more: vertical type (concrete foundation) is common
- If there is a loss of liquid due to evaporation, use a floating roof or expanding roof.
- Empty Space

Less than 500 [gal] (= 1.9 [m^3]): 15% of the volume
More than 500 [gal] (= 1.9 [m^3]): 10% of the volume

② Capacity

- Feed tank / product tank: For 30 days in general (it is also necessary to consider logistics)
- General storage tank: 1.5 times the volume of the receiving equipment.

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4. Storage Tanks

[Reference] Horizontal Drum ("Kagaku Souchi Binran", *In Japanese*: "Chemical Equipment Handbook" Revised 2nd ed., p. 441)

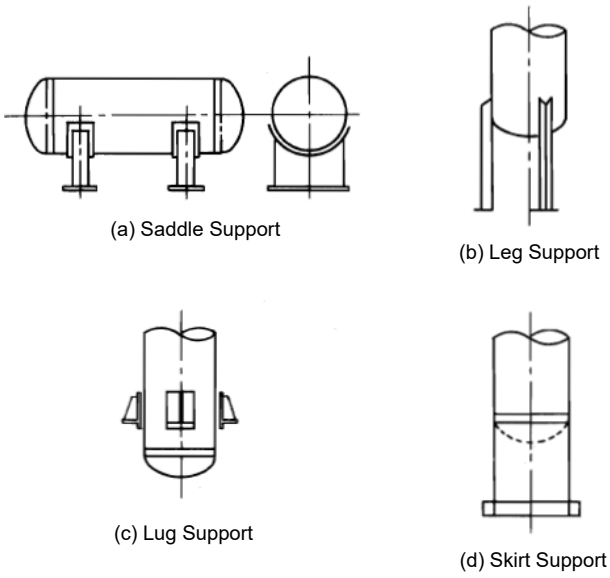

Figure 11.36 Support Method of Cylindrical Tanks

Solutions for R&D to Design

Conclusion

- When finally ordering the equipment, it is naturally necessary to determine the specifications after carrying out detailed design. On the other hand, when constructing a new process or remodeling existing facilities, rather than taking time to obtain the most accurate results in the initial stage of examination, it is in general required to give results in a short time since approximate values are acceptable.
- “Rules of Thumb” are suitable for such purposes, and in this document, the information considered to be useful focusing on “Pressure vessels” was summarized.
- In reports 1 to 4, only the main pieces of equipment were covered, and there are various “Rules of Thumb” for other equipment and piping and the like. It is very useful to understand and utilize them.