EQUIPMENT DESIGN

LECTURE 12-13
TANKS, VESSELS & DRUMS - MECHANICAL DESIGN

Requirements for Sizing & Specification

- **Tanks and General Pressure Vessels**
  - Type (Cone roof, floating, cylindrical PV)
  - Capacity (m^3)
  - Length, height, diameter (m) [aspect ratio]
  - Operating/Design Pressure, temperature
  - Orientation (vertical, horizontal, spherical)
  - Nozzles – size (NB), type, rating and location
    - Inlets, outlets, drains
    - Instruments (LGs, P, L, T), sampling, PVRV
    - Foam entry points (storage tanks)
  - Supports (Saddle, legs, plinths, pads)
  - Materials selection

Basic Mechanical Details

- vessel openings (nozzles, stub ends)
  - compensation
- support design (saddles, ladders, walkways)
- flanges and ratings
  - flat face (FF)
  - raised face (RF)
  - slip-on/Van Stone
  - ring
  - spigot/socket
- internals (weirs, supports, plates, distributors etc.)
- materials of construction/gasketing/finishing

Nozzles / Entries

Entry way

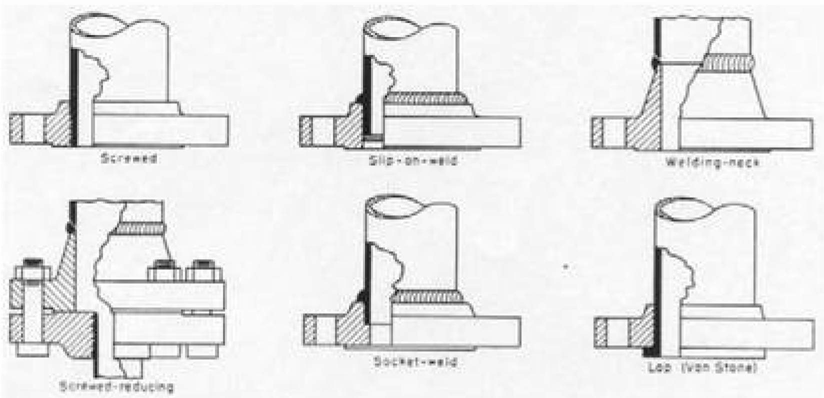
Standard nozzle

Nozzles

Stainless steel nozzle & welded neck flange

(Std ANSI 150)

Flange types



- **Screwed**: General service
- **Slip-on**: Moderate service conditions
- **Welding neck**: High P, T applications
- **Socket weld**: Small diameter pipe
- **Lap**: where frequent dismantling occurs

Pipe/Nozzle size estimation

- Based on velocity and phase
  - Liquid: 1-3m/s, 0.5 kPa/m
  - Vapour: 15-30 m/s, 0.02% line P
- Based on Genereaux (1937)
  - Carbon steel $d_{OPT} = 282\, G^{0.52} \rho^{-0.37}$
  - Stainless steel $d_{OPT} = 226\, G^{0.50} \rho^{-0.35}$

$G = kg/s \quad \rho = kg/m^3$

- Choose closest standard size pipe (see Perry)

LIQUID STORAGE TANKS : Vertical cylindrical tanks, with flat bases and conical roofs, are universally used for the bulk storage of liquids at atmospheric pressure. Tank sizes vary from a few hundred gallons (tens of cubic metres) to several thousand gallons (several hundred cubic metres). The minimum wall thickness required to resist the hydrostatic pressure can be calculated from the following equations:

$$e_s = \frac{\rho_L H_L g}{2 f_t J} \frac{D_t}{10^3} \qquad (13.130)$$

where e_s = tank thickness required at depth H_L, mm,
H_L = liquid depth, m,
ρ_L = liquid density, kg/m^3,
J = joint factor (if applicable),
g = gravitational acceleration, 9.81 m/s^2,
f_t = design stress for tank material, N/mm^2,
D_t = tank diameter, m.

GENERAL DESIGN CONSIDERATIONS OF PRESSURE VESSELS

1. **Design pressure** : $P_{design} = 1.2 \, P_{operating}$
2. **Design temperature** : The strength of metals decreases with increasing temperature so the maximum allowable design stress will depend on the material temperature. The design temperature at which the design stress is evaluated should be taken as the maximum working temperature of the material, with due allowance for any uncertainty involved in predicting vessel wall temperatures.
3. **Materials** : Pressure vessels are constructed from plain carbon steels, low and high alloy steels, other alloys, clad plate, and reinforced plastics. Selection of a suitable material must take into account the suitability of the material for fabrication (particularly welding) as well as the compatibility of the material with the process environment.

4. **Design stress (nominal design strength):** Typical design stress values for some common materials are shown in Table 13.2, These may be used for preliminary designs.
5. **Welded joint efficiency, and construction categories** : The strength of a welded joint will depend on the type of joint and the quality of the welding. The soundness of welds is checked by visual inspection and by non-destructive testing (radiography). Typical values are shown in Table 13.3.
6. **Corrosion allowance** : 1 mm for dry hydrocarbons, 2 mm for wet hydrocarbons, 3 mm and more for aqueous solutions.

7. Design loads : *Major loads*

1. Design pressure: including any significant static head of liquid.
2. Maximum weight of the vessel and contents, under operating conditions.
3. Maximum weight of the vessel and contents under the hydraulic test conditions.
4. Wind loads.
5. Earthquake (seismic) loads.
6. Loads supported by, or reacting on, the vessel.

Subsidiary loads

1. Local stresses caused by supports, internal structures and connecting pipes.
2. Shock loads caused by water hammer, or by surging of the vessel contents.
3. Bending moments caused by eccentricity of the centre of the working pressure relative to the neutral axis of the vessel.
4. Stresses due to temperature differences and differences in the coefficient expansion of materials.
5. Loads caused by fluctuations in temperature and pressure.

8. Minimum practical wall thickness : There will be a minimum wall thickness required to ensure that any vessel is sufficiently rigid to withstand its own weight, and any incidental loads. As a general guide the wall thickness of any vessel should not be less than the values given below; the values include a corrosion allowance of 2 mm

Vessel diameter (m)	Minimum thickness (mm)
1	5
1 to 2	7
2 to 2.5	9
2.5 to 3.0	10
3.0 to 3.5	12

Table 13.2. Typical design stresses for plate
(The appropriate material standards should be consulted for particular grades and plate thicknesses)

Material	Tensile strength (N/mm^2)	Design stress at temperature °C (N/mm^2)									
		0 to 50	100	150	200	250	300	350	400	450	500
Carbon steel (semi-killed or silicon killed)	360	135	125	115	105	95	85	80	70		
Carbon-manganese steel (semi-killed or silicon killed)	460	180	170	150	140	130	115	105	100		
Carbon-molybdenum steel, 0.5 per cent Mo	450	180	170	145	140	130	120	110	110		
Low alloy steel (Ni, Cr, Mo, V)	550	240	240	240	240	240	235	230	220	190	170
Stainless steel 18Cr/8Ni unstabilised (304)	510	165	145	130	115	110	105	100	100	95	90
Stainless steel 18Cr/8Ni Ti stabilised (321)	540	165	150	140	135	130	130	125	120	120	115
Stainless steel 18Cr/8Ni Mo $2\frac{1}{2}$ per cent (316)	520	175	150	135	120	115	110	105	105	100	95

Table 13.3. Maximum allowable joint efficiency

Type of joint	Degree of radiography		
	100 per cent	spot	none
Double-welded butt or equivalent	1.0	0.85	0.7
Single-weld butt joint with bonding strips	0.9	0.80	0.65

THE DESIGN OF THIN-WALLED VESSELS UNDER INTERNAL PRESSURE

1. **Cylinders and spherical shells :** The equations for the minimum thickness of cylinder and sphere can be obtained from equations 13.9 and 13.40 respectively:

$$e = \frac{P_i D_i}{2Jf - P_i} + c \qquad (13.39a)$$

$$e = \frac{P_i D_i}{4Jf - 1.2P_i} + c \qquad (13.40b)$$

Where,

P : Design Pressure D : Diameter C: corrosion allowance

J : Welding joint factor f : Design stress

THE DESIGN OF THIN-WALLED VESSELS UNDER INTERNAL PRESSURE

2. **Heads and closures :** The ends of a cylindrical vessel are closed by heads of various shapes. The principal types used are:

1. Flat plates and formed flat heads; Figure 13.9.
2. Hemispherical heads; Figure 13.10a.
3. Ellipsoidal heads; Figure 13.106.
4. Torispherical heads; Figure 13.10c. :

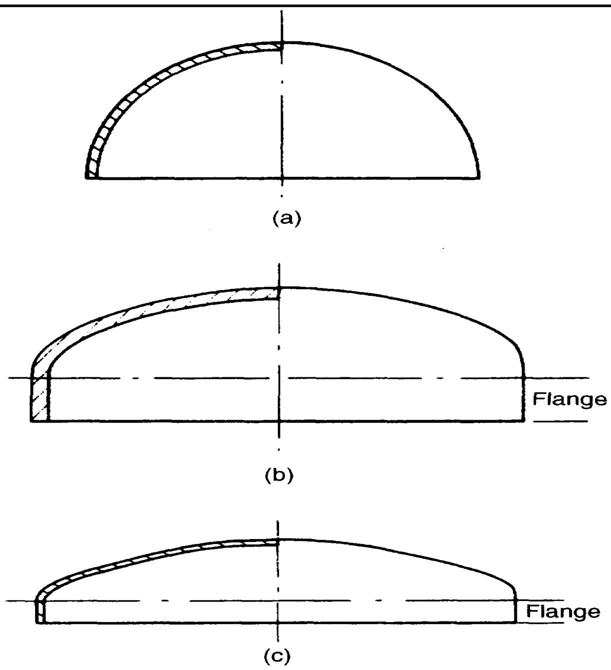


Figure 13.10. Domed heads (*a*) Hemispherical (*b*) Ellipsoidal (*c*) Torispherical

3. **Design of flat ends :** The thickness required will depend on the degree of constraint at the plate periphery. The minimum thickness required is given by:

$$e = C_p D_e \sqrt{\frac{P_i}{f}} \qquad (13.42)$$

where C_p = a design constant, dependent on the edge constraint,
D_e = nominal plate diameter,
f = design stress.

The values of the design constant and nominal diameter for the typical designs shown in Figure 13.9.

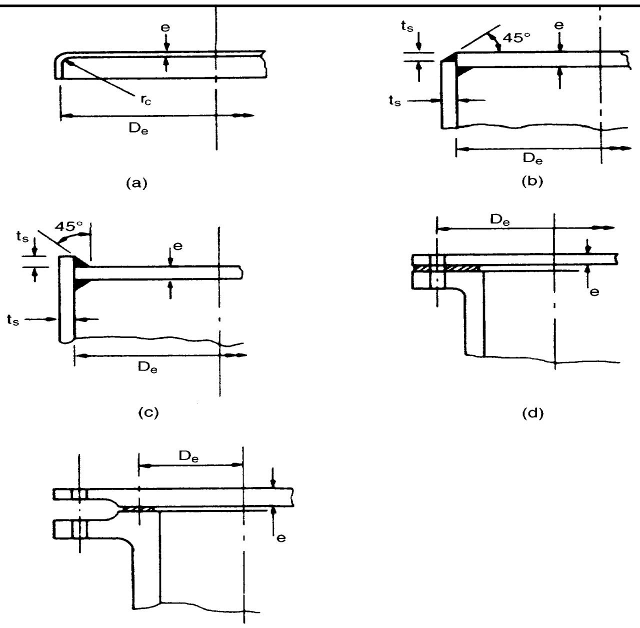


Figure 13.9. Flat-end closures (*a*) Flanged plate (*b*) Welded plate (*c*) Welded plate (*d*) Bolted cover (*e*) Bolted cover

3. Design of domed ends :

1. *Hemispherical heads :* $e = 0.6\, e_{shell}$
2. *Ellipsoidal heads :* Most standard ellipsoidal heads are manufactured with a major and minor axis ratio of 2 : 1 . For this ratio, the following equation can be used to calculate the minimum thickness required:

$$e = \frac{P_i D_i}{2Jf - 0.2P_i} \qquad (13.43)$$

3. *Torispherical heads*

$$e = \frac{P_i R_c C_s}{2fJ + P_i(C_s - 0.2)} \qquad (13.44)$$

where C_s = stress concentration factor for torispherical heads $= \frac{1}{4}(3 + \sqrt{R_c/R_k})$,
R_c = crown radius,
R_k = knuckle radius.

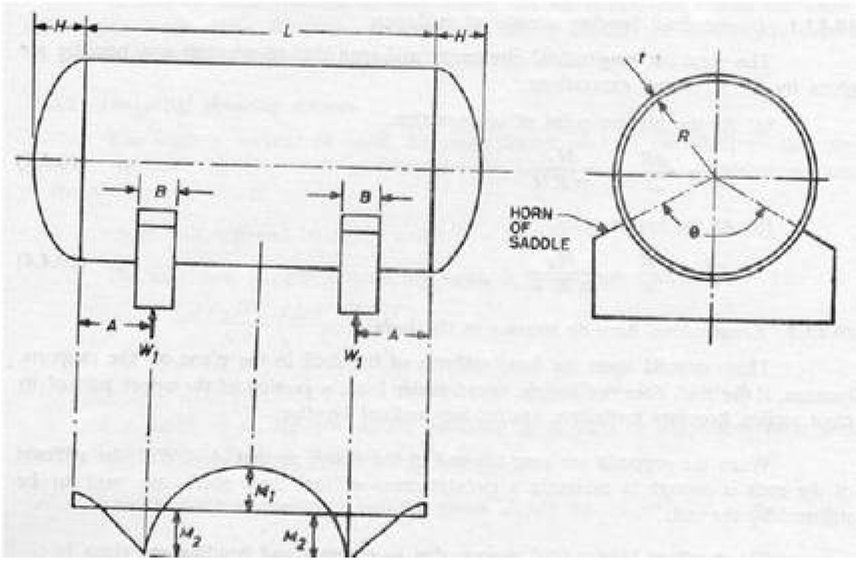
The ratio of the knuckle to crown radii should not be less than 0.06, to avoid buckling; and the crown radius should not be greater than the diameter of the cylindrical section. Any consistent set of units can be used with equations 13.43 and 13.44. For formed heads (no joints in the head) the joint factor J is taken as 1.0.

Vessel Supports

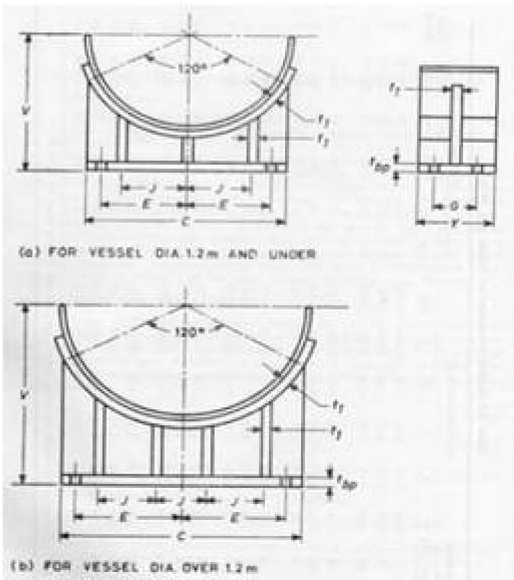
Saddle Support

Welded legs

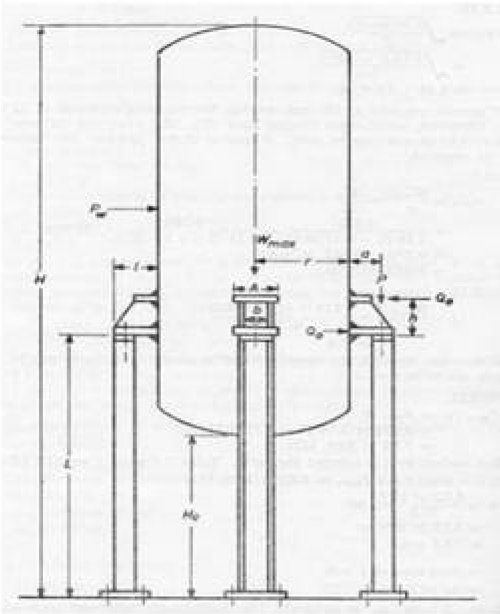
Saddle supports



Saddle support design



Leg support designs



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APPENDIX H 1001

Vessel data sheet	(PROCEED)	Equipment No. (Tag)
		Descript. (Func.)
		Sheet No.

Operating Data

						1
						2
No. REQUIRED		CAPACITY				3
SPECIFIC GRAVITY OF CONTENTS		COMPUTED (yes or no)				4

	SHELL	JACKET FULL/HALF COIL	INTERNAL COIL	5
CONTENTS				6
DIAMETER				7
LENGTH				8
DESIGN CODE				9
MAX. WORKING PRESSURE				10
DESIGN PRESSURE				11
MAX. WORKING TEMP				12
DESIGN TEMP				13
TEST PRESSURE (HYDROSTATIC)				14
TEST PRESSURE (AIR)				15
MATERIALS				16
JOINT FACTOR				17
CORROSION ALLOWANCE				18
THICKNESS				19

END TYPE		THICKNESS		JOINT FACTOR			20
END TYPE		THICKNESS		JOINT FACTOR			21
TYPE OF SUPPORT		THICKNESS		MATERIAL			22
WIND LOAD DESIGN		RADIOGRAPHY %		STRESS RELIEF			23
INTERNAL BOLTS MATERIAL		TYPE		NUTS			24
EXTERNAL BOLTS MATERIAL		TYPE		NUTS			25
INSULATION (SEP. ORDER)		INSULATION FITTING ATTACHMENT BY					26
GASKET MATERIAL		INSPECTION BY					27
PAINTING							28
WEIGHT		EMPTY					29
FULL OF LIQUID		OPERATING					30
INTERNALS and EXTERNALS		DATE OF ENQUIRY		DATE OF ORDER			31
ORDER No.		DRG. No.					32
MANUFACTURER							33
REMARKS AND NOTES:- UNLESS OTHERWISE STATED ALL FLANGE BOLT HOLES TO BE							34
OFF-CENTRE OF VESSEL CENTRE LINES N/S and E/W (NOT RADIALLY)							35
							37
							38
							39
							40

A										41
B										42
C										43
D										44
E										45
F										46
G										47
H										48
H										49
K										50
K										51
M										52
N										53
P										54
REF	No.	DUTY	NOM BORE	PIPE WALL	TYPE	CLASS	MATERIAL	BRANCH	REMARKS	55
BRANCH			mm/Ins	THICKNESS	RANGE SPEC			COMPEN'N		56
										57

Prepared				3				6				58
Checked				2				5				59
Approved				1				4				60
	Date	Engineering	Process	REV	By	Appr.	Date	REV	By	Appr.	Date	61

Service	Company	Address	62
Equipment No.			63
Project No.			64