Perancangan alat proses

Oleh : Indah Prihatiningtyas D.S

1. **Vessel overview dan hole - reinforcement**
2. **STIFFENER/ Penguat keliling bejana"**
3. **Support and design of support**
4. **Design of support – Saddle support**
5. **Heat exchanger**

PERANCANGAN ALAT PROSES

Vessel – overview dan hole - reinforcement

Oleh : Indah Prihatiningtyas D.S

VESSEL

(a container) handling liquids and gasses

- **Autoclave:** high pressure vessel with agitation and heating sources
- **Distillation column:** vessel containing a series of vapor-liquid contractors
- **Heat exchanger:** vessel for the transfer of heat

Open Tanks:
- Surge tanks between operations
- As settling tanks, decanters. Reservoirs
- Cheaper than covered or closed vessel

Closed Tanks:
- Combustible fluids, fluid emitting fluids, gasses (stored)
- Dangerous chemical (aced, caustic)

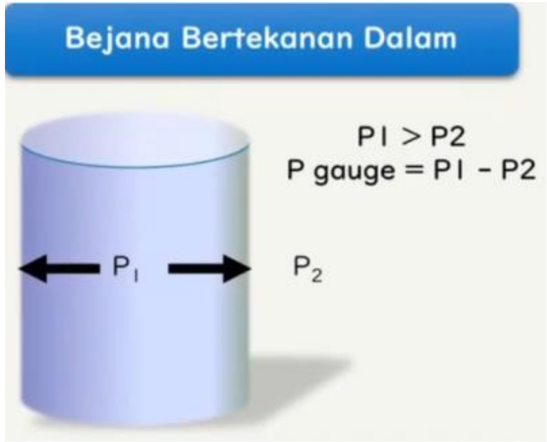
Spherical and Modified Vessel
- Storage container for large volumes
- Moderate pressure
- Gasses storage

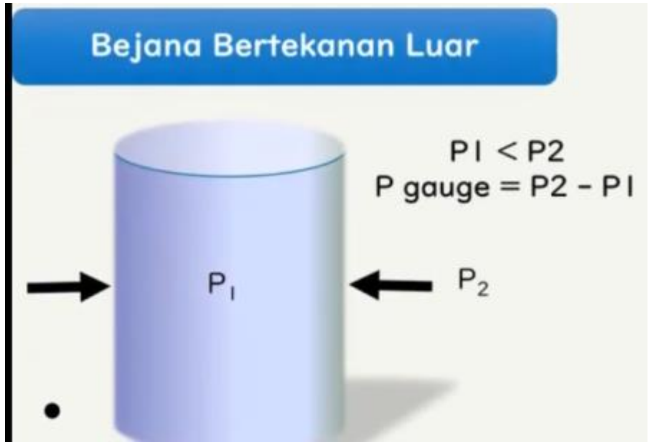
Cylindrical Vessel with Formed Ends
- Stronger design
- Less than 12 ft in diameter if shipped by rail
- 35 ft in diameter and 200 ft in length
- The formed head include the hemispherical, elliptical dished, tori spherical, conical, and standard dished

Cylindrical Vessel with Flat Bottoms and Conical or Domed Roofs
- The most economical design
- Tanks with conical roofs = limited to essentially atmospheric pressure
- Tanks with domed roofs = 2,5 to 15 lb/in^2, smaller diameter and greater

VESSEL

(a container) handling liquids and gasses





Vertikal
- Ruang lebih kecil
- Mudah mendistribusikan fluida

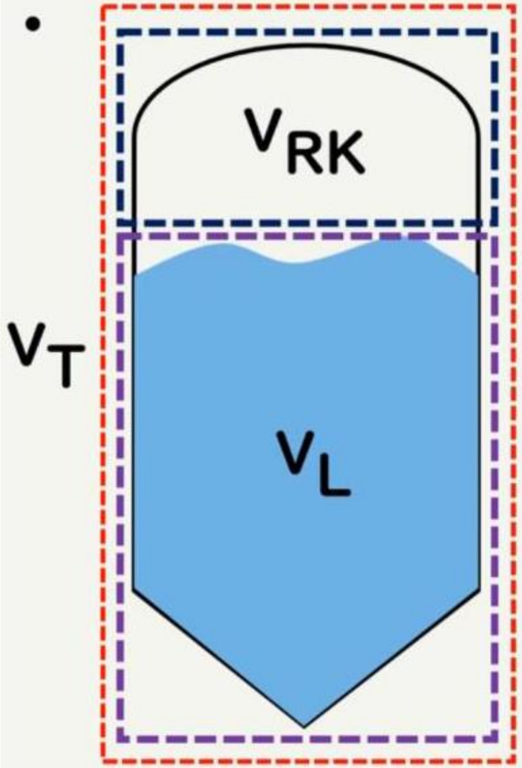
Horizontal
- Memperluas cross section
- Mempermudah pembersihan internal

Bejana Pendek	Bejana Panjang	Bejana Tipis	Bejana Tebal
$Ls/d \leq 5$	$Ls/d \geq 5$	$Ts < 5\%\ d$	$Ts > 5\%\ d$

VESSEL

(a container) handling liquids and gasses

1. Penentuan volume bejana

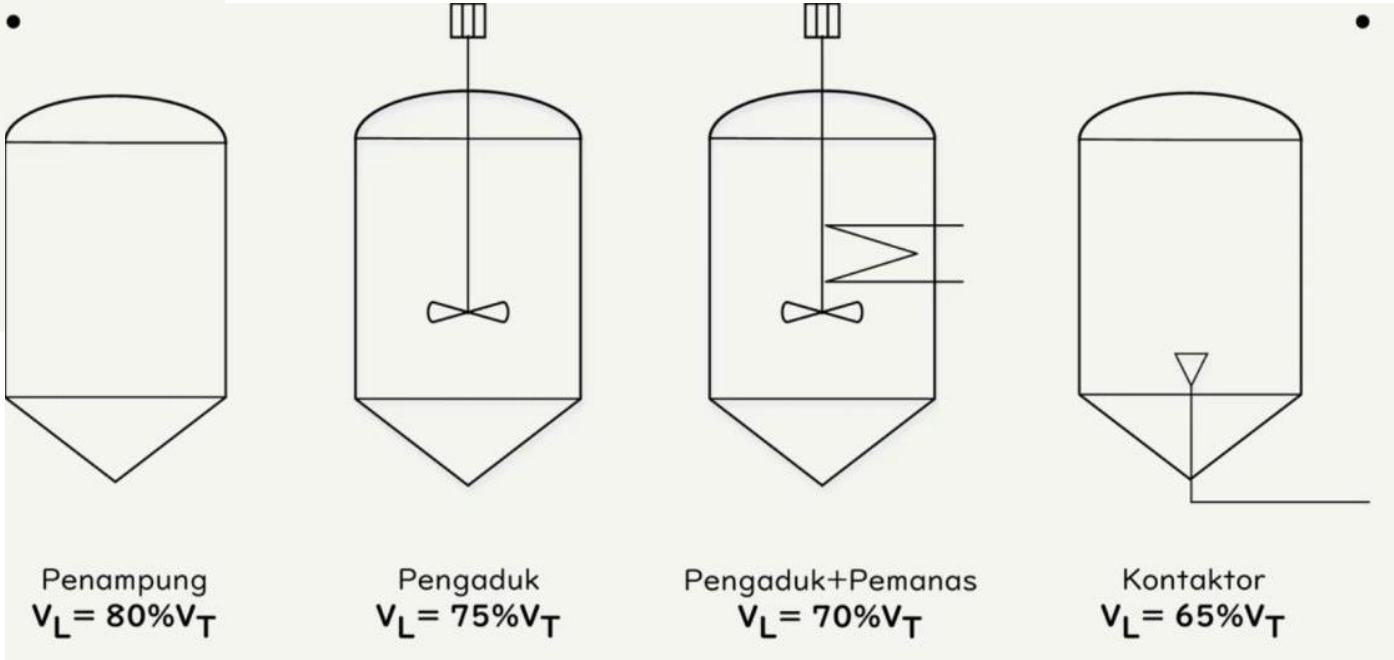


$$V_T = V_L + V_{RK}$$

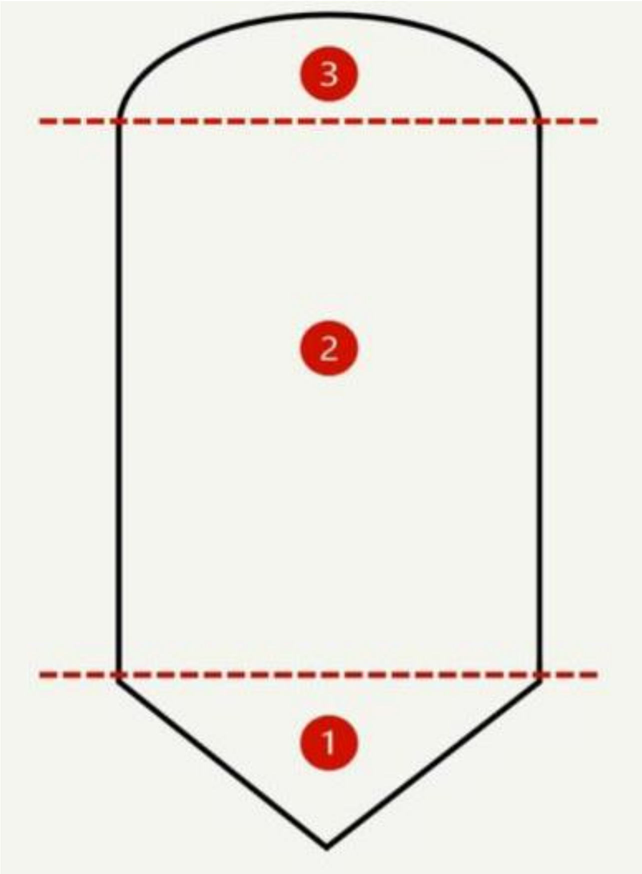
Volume total bejana = Volume liquid + Volume ruang kosong

$$V_L = Q \times \theta$$

Volume liquid = laju alir x waktu tinggal



Penentuan volume bejana



Bagian 3 : tutup atas bejana

V_3

Bagian 2 : silinder (badan) bejana

V_2

Bagian 1 : tutup bawah bejana

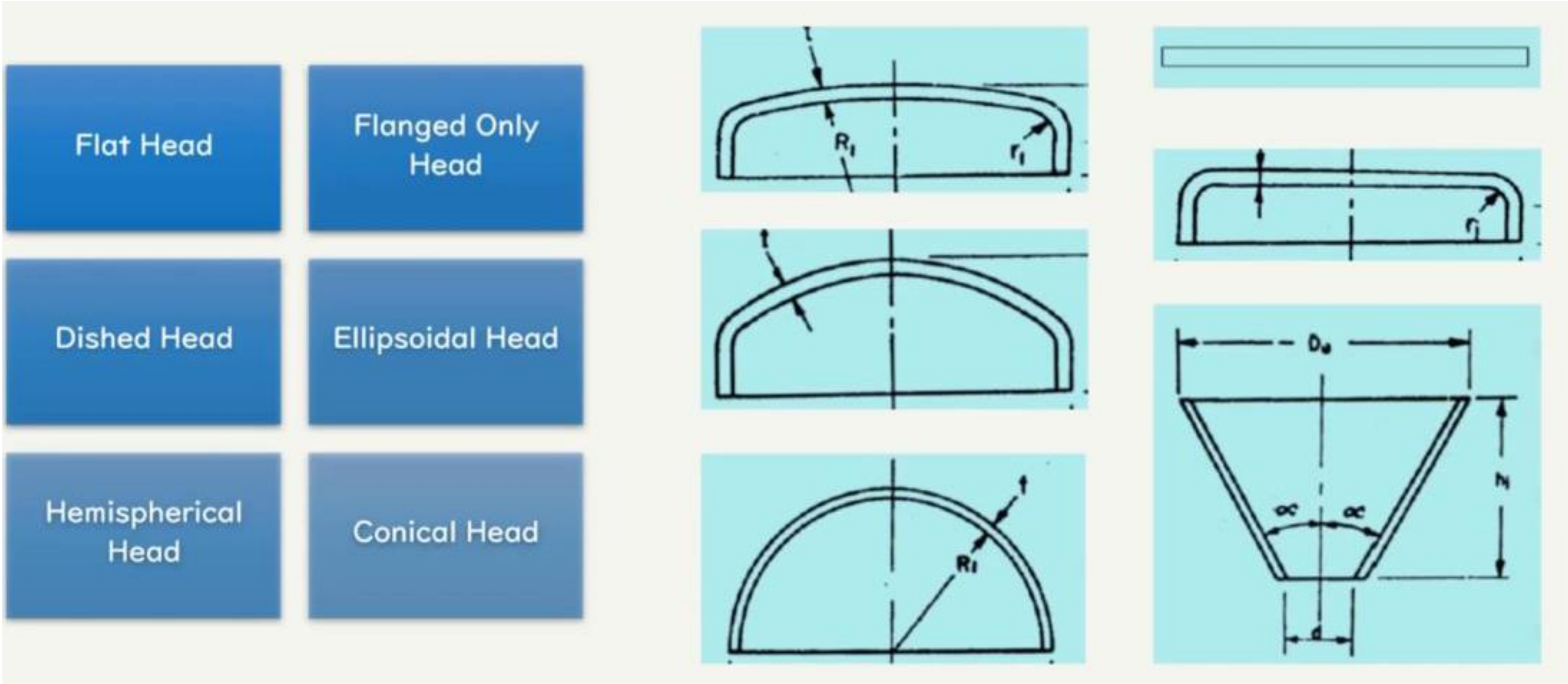
V_1

$$V_T = V_1 + V_2 + V_3$$

Volume total bejana = Volume tutup bawah + Volume silinder + Volume tutup atas

V_1, V_3 } Rumus volume berubah-ubah tergantung bentuk tutup atas dan tutup bawah

Penentuan volume bejana



2. Penentuan dimensi dasar bejana

Bejana dengan tutup bawah CONISH/CONICAL dan tutup atas STANDARD DISHED

Jika diminta menghitung dimensi bejana maka hitunglah:

- Volume total
- Volume liquid
- Volume ruang kosong
- Diameter
- Tinggi silinder
- Tinggi tutup bawah
- Tinggi tutup atas
- Tinggi total bejana

$$V_T = \frac{\pi d^3}{24\ tg \frac{1}{2}\alpha} + \frac{\pi d^2 L_s}{4} + 0{,}0847 d^3$$

d = diameter dalam bejana (ft)

L_s = tinggi silinder (ft)

α = sudut puncak tutup conical

Dimensi tinggi tutup atas dan tutup bawah

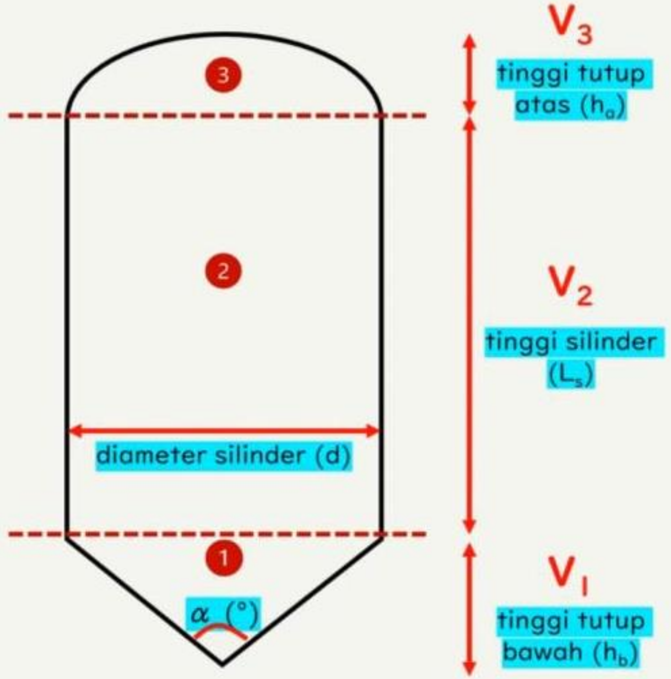
$$h_a = 0{,}169\ d$$

$$h_b = \frac{{}^1/_2\, d}{tg\ {}^1/_2\, \alpha}$$

Total tinggi bejana

$$H = h_b + L_s + h_a$$

Dalam satuan **ft**



$$V_1 = \frac{\pi d^3}{24\ tg \frac{1}{2}\alpha}$$

$$V_2 = \frac{\pi d^2 L_s}{4}$$

$$V_3 = 0{,}0847 d^3$$

$$V_T = \frac{\pi d^3}{24\ tg \frac{1}{2}\alpha} + \frac{\pi d^2 L_s}{4} + 0{,}0847 d^3$$

3. Penentuan tebal bejana

Penentuan tebal silinder dan tebal tutup (atas dan bawah).

TEBAL SILINDER

- $$t_s = \frac{P_i\, d_i}{2(fE - 0,6P_i)} + C$$

↓

t_s standard

↓

$$d_o = d_i + 2t_s$$

↓

d_o standard

↓

$$d_{i\ baru} = d_{o\ standard} - 2t_s$$

t_s = tebal silinder (inch)

P_i = internal pressure (psig)

d_i = inside diameter (in)

d_o = outside diameter (in)

f = allowable stress (psig)

E = efisiensi pengelasan (%)

C = corrosion factor (in)

$C = {}^{1}/_{16}$ sampai dengan ${}^{4}/_{16}$

→ semakin korosif

Penentuan tebal bejana

Penentuan tebal silinder dan tebal tutup (atas dan bawah).

Mencari nilai f (allowable stress)

Item 4. Maximum Allowable Stress Values in Tension for High-alloy Steel, in Pounds per Square Inch

(Extracted from the 1956 Edition of the *ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels*, with Permission of the Publisher, th

Material and Specification Number	Grade	Type	Nominal Composition	Spec. Min Tensile	Notes	For Metal Temperatures Not Exceeding Deg F: −20 to 100	200	300	400	500	600	650
Plate Steels												
SA-167	3	304	18 Cr—8 Ni	75,000	(1)	18,750	17,000	16,000	15,450	15,100	14,900	14,850
SA-167	3	304	18 Cr—8 Ni	75,000	....	18,750	16,650	15,000	13,650	12,500	11,600	11,200
SA-167	5	321	18 Cr—8 Ni-Ti	75,000	...	18,750	18,750	17,000	15,800	15,200	14,900	14,850
SA-167	6	347	18 Cr—8 Ni-Cb	75,000	...	18,750	18,750	17,000	15,800	15,200	14,900	14,850
SA-167	8	309	25 Cr—12 Ni	75,000	...	18,750	18,750	17,300	16,700	16,600	16,500	16,450
SA-167	10	310	25 Cr—20 Ni	75,000	(2)	18,750	18,750	18,500	18,200	17,700	17,200	16,900
SA-167	10	310	25 Cr—20 Ni	75,000	(3)	18,750	18,750	18,500	18,200	17,700	17,200	16,900
SA-167	11	316	18 Cr—10 Ni—2 Mo	75,000	...	18,750	18,750	17,900	17,500	17,200	17,100	17,050
SA-240	A	410	13 Cr	65,000	...	16,250	15,600	15,100	14,600	14,150	13,850	13,700
SA-240	B	...	15 Cr	70,000	...	17,500	17,500	16,300	15,650	15,100	14,600	14,300
SA-240	C	347	18 Cr—8 Ni-Cb	75,000	...	18,750	18,750	17,000	15,800	15,200	14,900	14,850
SA-240	D	430	17 Cr	70,000	(9)	17,500	17,500	16,300	15,650	15,100	14,600	14,300
SA-240	M	316	18 Cr—10 Ni—2 Mo	75,000	...	18,750	18,750	17,900	17,500	17,200	17,100	17,050
SA-240	O	405	12 Cr-Al	60,000	...	15,000	15,000	14,700	14,400	13,950	13,400	13,000
SA-240	S	304	18 Cr—8 Ni	75,000	(1)	18,750	17,000	16,000	15,450	15,100	14,900	14,850
SA-240	S	304	18 Cr—8 Ni	75,000	...	18,750	16,650	15,000	13,650	12,500	11,600	11,200
SA-240	T	321	18 Cr—8 Ni-Ti	75,000	...	18,750	18,750	17,000	15,800	15,200	14,900	14,850

Material and Specification Number	Grade	Type	700	750	800	850	900	950
Plate Steels								
SA-167	3	304	14,800	14,700	14,550	14,300	14,000	13,400
SA-167	3	304	10,800	10,400	10,000	9700	9400	9100
SA-167	5	321	14,800	14,700	14,550	14,300	14,100	13,850
SA-167	6	347	14,800	14,700	14,550	14,300	14,100	13,850
SA-167	8	309	16,400	16,200	15,700	14,900	13,800	12,500
SA-167	10	310	16,600	16,250	15,700	14,900	13,800	12,500
SA-167	10	310	16,600	16,250	15,700	14,900	13,800	12,500
SA-167	11	316	17,000	16,900	16,750	16,500	16,000	15,100
SA-240	A	410	13,400	13,100	12,750	12,100	11,000	8800
SA-240	B	...	13,900	13,500	13,100	12,500	11,700	9200
SA-240	C	347	14,800	14,700	14,550	14,300	14,100	13,850
SA-240	D	430	13,900	13,500	13,100	12,500	11,700	9200
SA-240	M	316	17,000	16,900	16,750	16,500	16,000	15,100
SA-240	O	405	12,450	11,800	11,000	10,100	9100	8000
SA-240	S	304	14,800	14,700	14,550	14,300	14,000	13,400
SA-240	S	304	10,800	10,400	10,000	9700	9400	9100
SA-240	T	321	14,800	14,700	14,500	14,300	14,100	13,850

Mencari nilai E (efisiensi pengelasan)

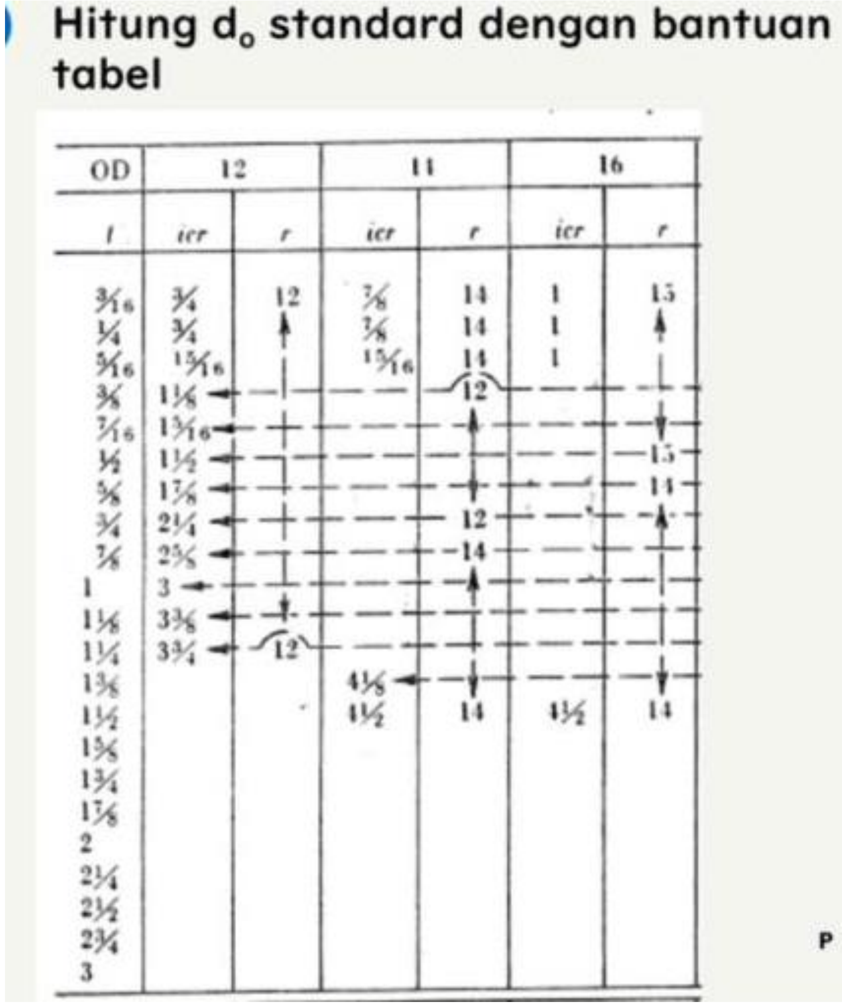
Table 13.2. Maximum Allowable Efficiencies for Arc- and Gas-welded Joints (11)

From the 1956 ASME Unfired-Pressure-Vessel Code with Permission of the American Society of Mechanical Engineers

Type of Joint	Limitations	Basic Joint Efficiency, per cent	Radiographed	Thermally Stress Relieved	Maximum Joint Efficiency, per cent
Double-welded butt joint	None		No	No	80
Single-welded butt joint with backing strip	Longitudinal joints not over 1¼ in. thick. No thickness limitation on circumferential joints.	80	No Yes Yes	Yes No Yes	85 90 95
Single-welded butt joint without backing strip	Circumferential joints only, not over ⅝ in. thick.	70	No No	No Yes	70 75
Double full-fillet lap joint	Longitudinal joints not over ⅜ in. thick. Circumferential joints not over ⅝ in. thick.	65	No No	No Yes	65 70
Single full-fillet lap joint with plug welds	Circumferential joints only, not over ⅝ in. thick; attachment of heads not over 24 in. in outside diameter to shells not over ⅝ in. thick.	60	No No	No Yes	60 65
Single full-fillet lap joint without plug welds	Only for attachment of heads convex to pressure to shells not over ⅝ in. thick, and for attachment of heads concave to pressure not over 24 in. in outside diameter to shells not over ¼ in. thick.	50	No No	No Yes	50 55

Penentuan tebal bejana

Penentuan tebal silinder dan tebal tutup (atas dan bawah).



Hitung d_o standard dengan bantuan tabel

OD	12		11		16	
t	icr	r	icr	r	icr	r
3/16	3/4	12	7/8	14	1	15
1/4	3/4		7/8	14	1	
5/16	15/16		15/16	14	1	
3/8	1 1/8			12		
7/16	1 3/16					
1/2	1 1/2					15
5/8	1 7/8					14
3/4	2 1/4			12		
7/8	2 5/8			14		
1	3					
1 1/8	3 3/8					
1 1/4	3 3/4	12				
1 3/8			4 1/8			
1 1/2			4 1/2	14	4 1/2	14
1 5/8						
1 3/4						
1 7/8						
2						
2 1/4						
2 1/2						
2 3/4						
3						

P

4. Penentuan internal pressure

P_i atau internal pressure yang memiliki satuan psig, dapat dihitung dengan 2 cara:

1. Densitas liquida ≤ 1 kg/m³ → $P_i = \rho \frac{(H - 1)}{144}$

ρ	= Densitas liquida pada temperature yang digunakan (lb/ft^3)
H	= Tinggi liquid di dalam bejana (ft)
P_i	= Internal pressure (psig)
144	= adalah factor konversi ft^2 ke in^2

$$H = L_{Ls} + h_b$$

L_{LS}	= tinggi liquid di dalam silinder (ft)
h_b	= tinggi tutup bawah (ft)

Penentuan internal pressure

2. Densitas liquida ≥ 1 kg/m³ → $P_i = P_{atmosferik} + P_{liquid}$

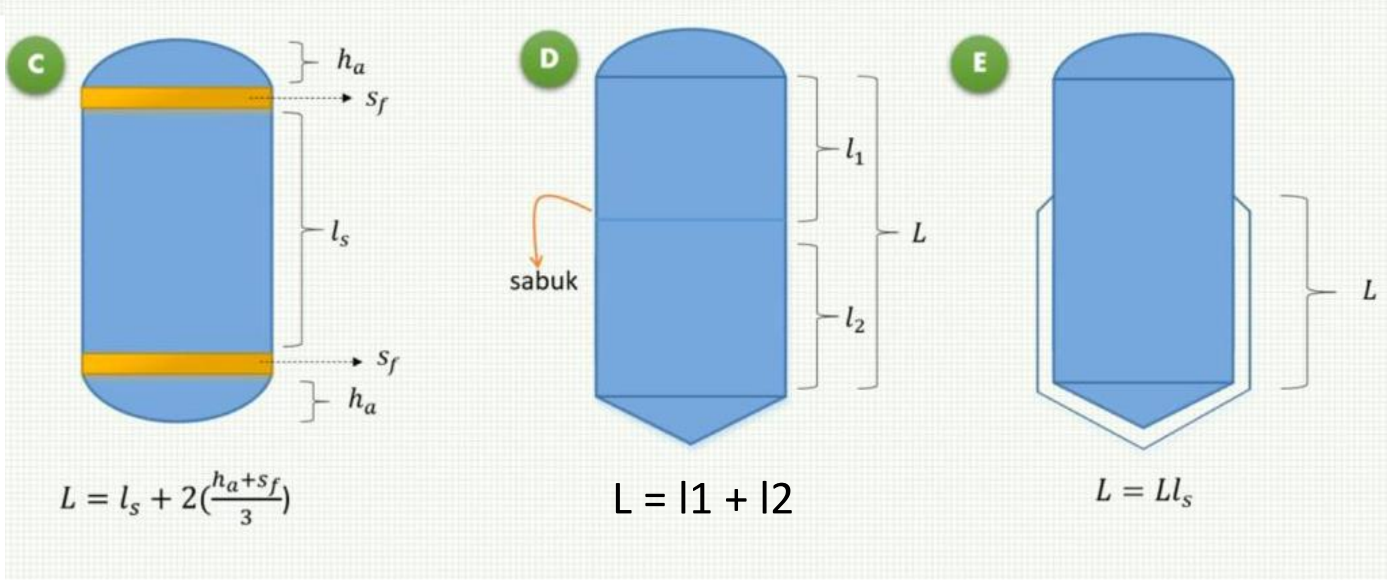
Pi	= Internal pressure (psig)
$P_{atmosferik}$	= Tekanan atmosferik (psig)
P_{liquid}	= Tekanan liquid (psig)

$$P_{liquid} = \rho_{liquid} \times g \times H$$

ρ_{liquid}	= Densitas liquida pada temperature yang digunakan (lb/ft^3)
H	= Tinggi liquid di dalam bejana (ft)
g	= Percepatan gravitasi (32,174 ft/s^2)
P_{liquid}	= Tekanan liquid atau tekanan bahan($lb/ft.s^2$)

→ Maka satuan P_{liquid} harus dikonversi dari $lb/ft.s^2$ ke psig

5. Merancang bejana – external pressure



Perancangan dimensi bejana Eksternal Pressure ⟶ TRIAL and Error

Sebagai pengevaluasi adalah $P_{allowable} > P_{teoritis}$

$$P_{teoritis} = P_2 - P_1 \text{ dan } P_{allowable} = \frac{B}{d_o/t_s} \; atau \; P_{allowable} = \frac{B}{100 \times \frac{r}{100 t_h}}$$

$t_s = tebal\ silinder\ hasil\ trial\ and\ error$
$d_o = diameter\ luar\ bejana$
$\text{B} = \text{konstanta didapat pada grafik 8.8}$
$r = radius\ dished$
$t_h = tebal\ tutup\ hasil\ trial\ and\ error$

STEP PERHITUNGAN TEBAL SILINDER:

1. Hitung $P_{teoritis} = P_2 - P_1$
2. Hitung $\frac{l}{d_0} = \frac{L}{d_i + 2\,t_s}$ dengan menebak t_s
3. Hitung $\frac{d_o}{t_s} = \frac{d_i + 2\,t_s}{t_s}$
4. Membaca grafik 8.8 untuk menentukan nilai B
5. Hitung $P_{allowable} = \frac{B}{d_o/t_s}$
6. Mendapatkan nilai t_s apabila $P_{allowable} > P_{teoritis}$ dan $\Delta P = 10 - 20\%\,;\ \Delta P = \frac{P_{allowable} - P_{teoritis}}{P_{teoritis}} \times 100\%$
7. Mendapatkan nilai t_s
8. Mencari $d_o\ dan\ d_{i\ baru}$
9. Mencari tebal tutup dengan metode yang sama

STEP PERHITUNGAN TEBAL TUTUP:

a. Standard Dished

$r = d_i\ atau\ r = d_i - 6\ inch$

1. Hitung $P_{teoritis} = P_2 - P_1$
2. Hitung $\frac{r}{100 t_h}$ dengan menebak t_h
3. Membaca grafik 8.8 untuk menentukan nilai B
4. Hitung $P_{allowable} = \frac{B}{100 \times \frac{r}{100 t_h}}$
5. Mendapatkan nilai t_h jika $P_{allowable} > P_{teoritis}$ dan $\Delta P = 10 - 20\%\,;\ \Delta P = \frac{P_{allowable} - P_{teoritis}}{P_{teoritis}} \times 100\%$

STEP PERHITUNGAN TEBAL TUTUP:

b. Conical

1. Hitung $P_{teoritis} = P_2 - P_1$
2. Hitung L dengan cara mencari $h_b = \frac{{}^1/_2 d_i}{tan\,{}^1/_2 \alpha}$
3. Hitung $\frac{l}{d_0} = \frac{L}{d_i + 2 t_h}$ dengan menebak t_h
4. Hitung $\frac{d_o}{t_h} = \frac{d_i + 2\,t_h}{t_h}$
5. Membaca grafik 8.8 untuk menentukan nilai B
6. Hitung $P_{allowable} = \frac{B}{d_o/t_h}$
7. Mendapatkan nilai t_h jika $P_{allowable} > P_{teoritis}$ dan $\Delta P = 10 - 20\%\,;\ \Delta P = \frac{P_{allowable} - P_{teoritis}}{P_{teoritis}} \times 100\%$

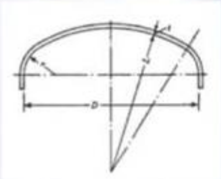
Merancang tangki bertekanan?

- Dimensi tangki ? L/D, material? Jenis head nya?

1. Kondisi operasi : Suhu, tekanan operasi, tekanan design
2. Jenis tangki (tekanan design) >>> horizontal / vertical >> horizontal maks 3500 gallon, head??
3. Dimensi tangki : volume dished, volume silinder, L/D
4. Menentukan material tangki, ketebalan tangki (allaow stress, eff. Pengelasan), check ketebalan untuk sambungan.
5. Ketebalan head

Dished Head (Torispherical)

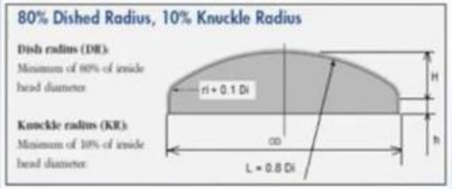
- Meridien terdiri dari "crown" dan "knuckle"
- "shallow" (crown radius > D_o silinder) atau "standard" (crown radius ≤ D_o silinder)
- Knuckle radius ≥ 3 x tebal & ≥ 6% D_i silinder
- Penutup tangki bertekanan 1- 15 atm



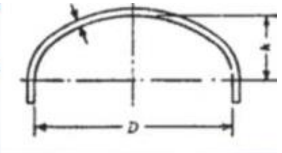
$$t = \frac{0.885PL}{SE - 0.1P}$$

And,

$$P = \frac{SEt}{0.885L + 0.1t}$$



Ellipsoidal/Elliptical Head

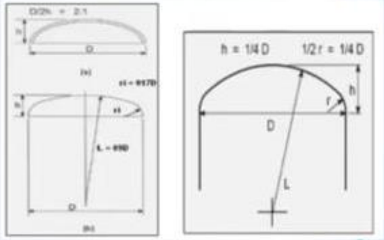


- Kekuatan setara dengan silinder tanpa sambungan
- Sumbu utama dua kali sumbu minor
- Penutup tangki bertekanan >15 atm

$$t = \frac{PD}{2SE - 0.2P}$$

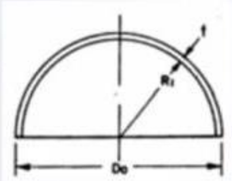
or

$$P = \frac{2SEt}{D + 0.2t}$$



Hemisperical Head

- Paling kuat, setara dengan dua kali ellipsoidal
- Fabrikasi paling mahal
- Fabrikasi tanpa sambungan tidak memungkinkan



a) When $t < 0.356R$ or $P < 0.665SE$ - (Thin Spherical or Hemispherical Heads):

$$t = \frac{PR}{2SE - 0.2P} \qquad 2.1$$

And,

$$P = \frac{2SEt}{R + 0.2t} \qquad 2.2$$

P (psig)	0–250	251–500	501 +
L/D	3	4	5

	Volume
Silinder	$(\pi/4)D^2L$
Dished head/ torispherical	$0.0778\ D^3$
Ellipsoidal/ Eliptical	$0.1309\ D^3$
Hemispherical	$(\pi/12)D^3$

ASTM/AISI Spec & Grade	Lowest Usual Service Temp.[3] °C	Thermal Conductivity, W/(m · °C) at noted mean temperature, °C					Example Applications	
		+95	+20	−45	−100	−195	Uses	Liquids Stored
Carbon Steels								
A333 Grades 1 & 6	−45	51	50				Welded pressure vessels and storage tanks, when weight and strength are not critical. Refrigeration and transport equipment.	Butane, Isobutane, Sulfur Dioxide, Ammonia, Propane, Propylene
A334 Grades 1 & 6	−45	51	50					
A442 Grades 55 & 60	−45	51	50					
A516 Grades 55, 60, 65, & 70[3]	−45	51	50					
A537[4]	−45	51	50					
Alloy Steels								
A517 Grade F	−45		38				Highly stressed pressure vessels. Tank trucks for handling LP gases.	LP Gases
A203 Grades A&B - 2¼% Ni	−60	42	39	36	34	21	Tanks, vessels, and piping for liquid propane.	Propane
A333 Grade 7 - 2¼% Ni	−60	42	39	36	34	21		
A334 Grade 7 - 2¼% Ni	−60	42	39	36	34	21		
Alloy Steels								
A203 Grades D&E - 3½% Ni	−100	39	37	33	31	18	Land-based storage of liquid propane, carbon dioxide, acetylene, ethane and ethylene.	Propane, Carbon Dioxide, Acetylene, Ethane, Ethylene
A333 Grade 3 - 3½% Ni	−100	39	37	33	31	18		
A334 Grade 3 - 3½% Ni	−100	39	37	33	31	18		
Stainless Steels								
AISI - 300 Series (Type 301)	−100	16	15	14	12	8		
Alloy Steels								
A333 Grade 8 - 9% Ni	−195	30	27	26	23	13	Large tonnage oxygen-producing equipment. Transportation and storage of methane, oxygen, nitrogen, and argon.	Ethylene, Methane, Oxygen, Carbon Monoxide, Nitrogen, LNG, Argon
A334 Grade 8 - 9% Ni	−195	30	27	26	23	13		
A353 Grade 8 - 9% Ni	−195	30	27	26	23	13		
ASME Code Case 1308 - 9% Ni								

Ketebalan Shell

- Berdasarkan standar ASME VIII Devisi 1, ketebalan shell berdasar Internal pressure:

1. Circumferential stress : Sambungan memanjang (longitudinal welds)

Ketika P< 0,385 S.E

$$t = \frac{PR}{(SE - 0.6P)}$$

$$P = \frac{SEt}{(R + 0.6t)}$$

2. Longitudinal stress : Sambungan melingkar (circumferential welds)

Ketika P< 1,25 S.E

$$t = \frac{PR}{(2SE + 0.4P)}$$

$$P = \frac{2SEt}{(R - 0.4t)}$$

Silinder tebal , ASME VIII

- Tekanan lebih 3000 psi
- Ketebalan shell

1. Circumferential stress : Sambungan memanjang (longitudinal welds)

Ketika P> 0,385 S.E

$$t = R\left(Z^{\frac{1}{2}} - 1\right) \quad \text{Where} \quad Z = \frac{(SE + P)}{(SE - P)}$$

$$P = SE\left[\frac{(Z - 1)}{(Z + 1)}\right] \quad \text{Where} \quad Z = \left[\frac{(R + t)}{R}\right]^2$$

2. Longitudinal stress : Sambungan melingkar (circumferential welds)

Ketika P> 1,25 S.E

$$t = R\left(Z^{\frac{1}{2}} - 1\right) \quad \text{Where} \quad Z = \left(\frac{P}{SE}\right) + 1$$

$$P = SE(Z - 1) \quad \text{Where} \quad Z = \left[\frac{(R + t)}{R}\right]^2$$

Ketebalan					
		shell	=	5/8	inch
		head	=	1	inch

Contoh hasil design tangki bertekanan < 15 psi

Perancangan tangka untuk isobutan cair pada suhu 30 ^{o}C dengan kapasitas 500 m^3 menggunakan standar ASME :

- **Storage tank, cylinder with torispherical head**
- **Design code : ASME section VIII**
- **Tangki penyimpanan n-butana :**
  - **Kapasitas : 110 m3**
  - **L/D : 3**
  - **Jumlah : 5**
- **Kondisi operasi :**
  - **Tekanan : 5,906 atm**
  - **Temperature : 40 ^{o}C**
- **Bahan konstruksi : Carbon steel SA 516-55**
- **Type : Silinder horisontal**

  Dished head/torispherical
- **Dimensi : Diameter : 3,5 m = 11,57 ft**

  Panjang : 10,6 m = 34,7 ft

Lanjut materi 15

Hole and Reinforcement

sebagai tempat keluar masuknya bahan dan produk (inlet outlet)

- Liquid
- Solid
- Gas

Nozzle

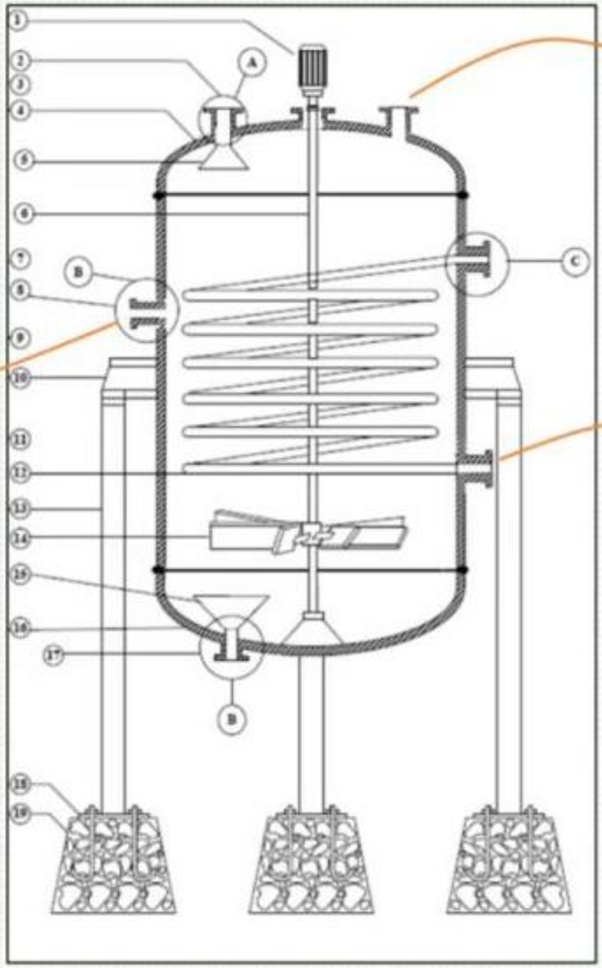
sebagai tempat keluar masuknya tangan operator, untuk perawatan atau perbaikan vessel/peralatan proses

Manhole

sebagai tempat keluar masuknya operator, untuk perawatan atau perbaikan vessel/peralatan proses

Handhole

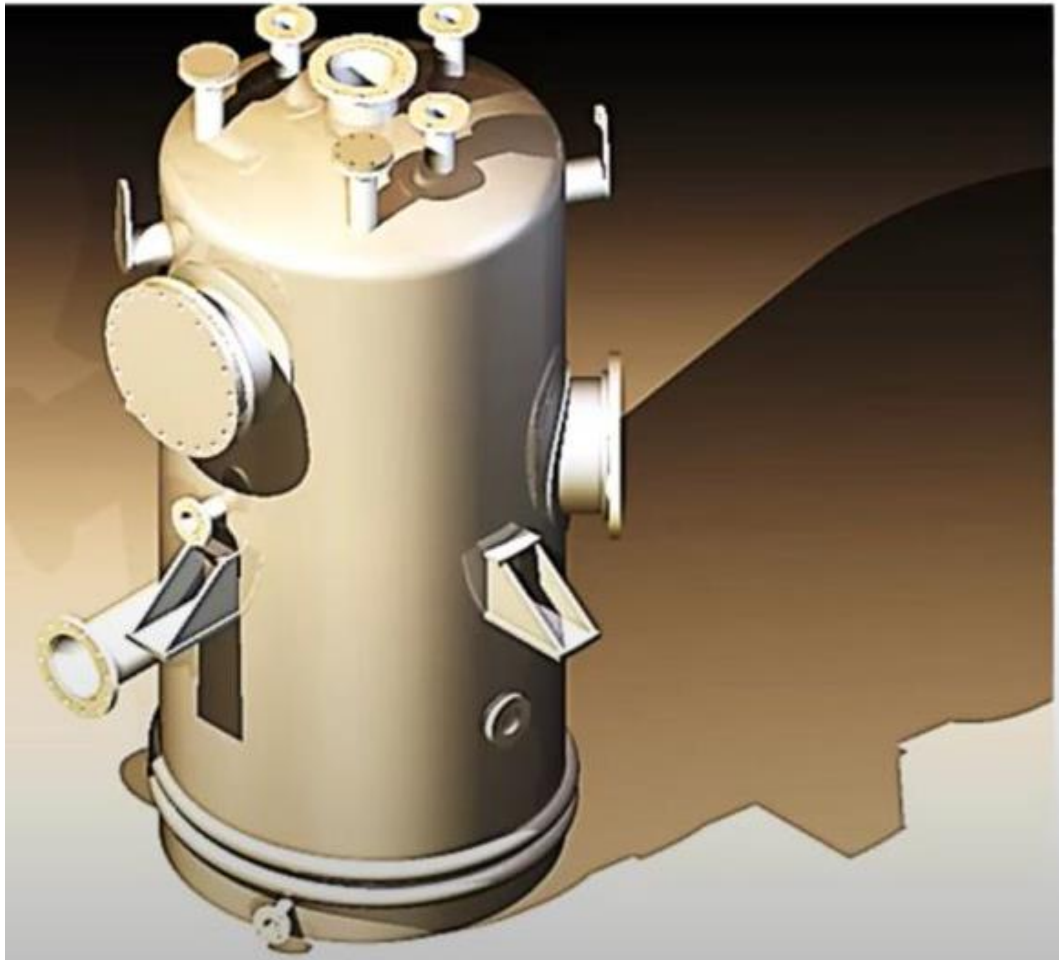
Manhole
d = 20 / 24 inch

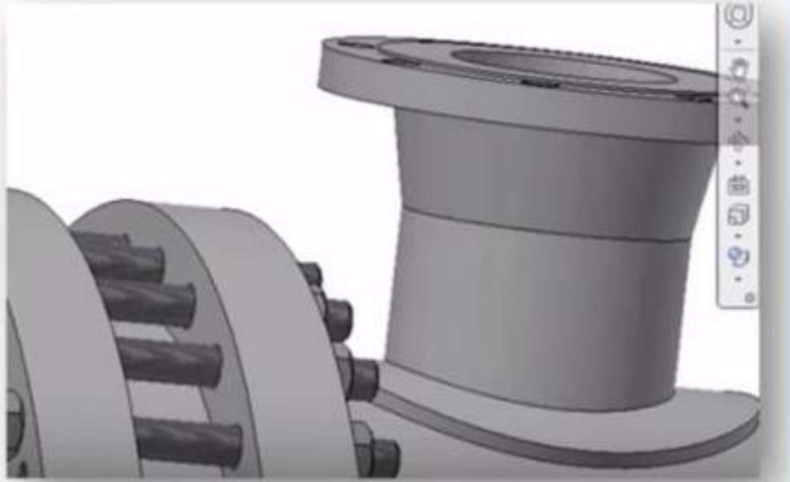


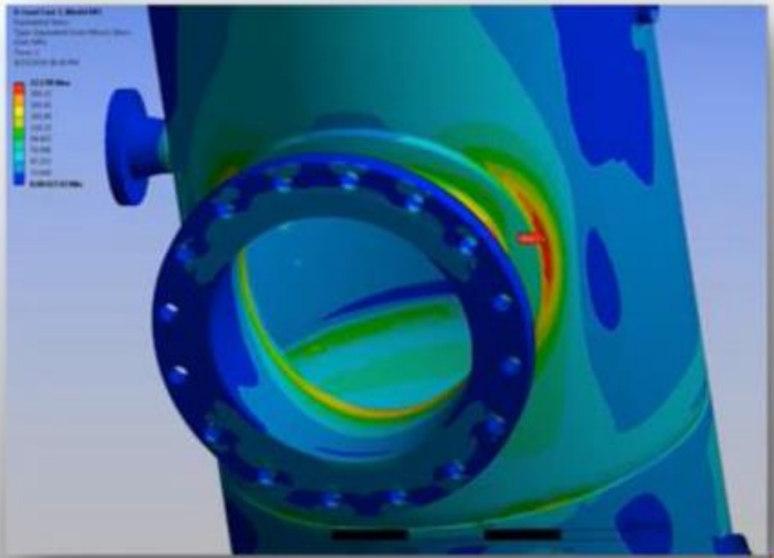
Nozzle
Liquid ± 2 inch
Solid ± 2 inch
Gas < 2 inch

Handhole
d ± 6 inch

Nozzle Reinforcing Pads





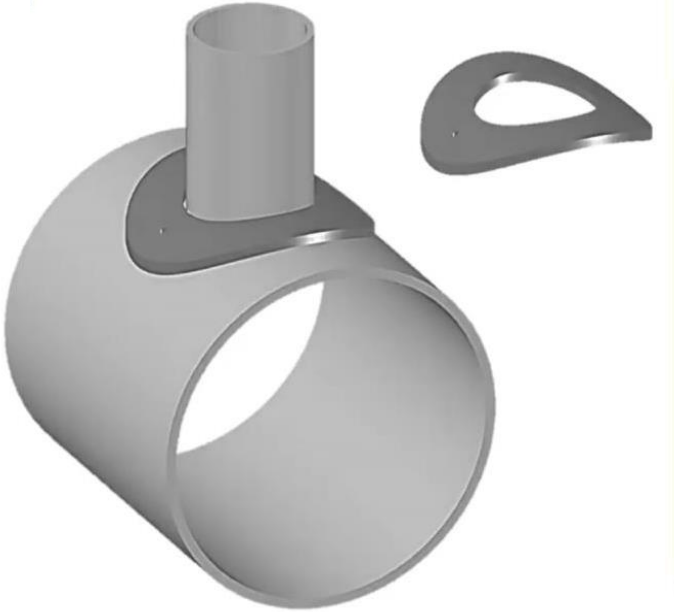


Nozzle Reinforcing Pads

Nozzles are installed on pressure vessels by cutting a hole in the vessel shell, then install the nozzle by welding.

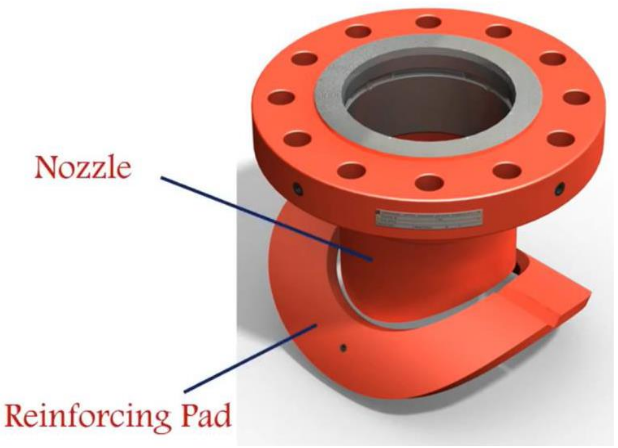
Due to metal removal and welding, a stress concentration or risers is foreseen at the intersection weld joint, between nozzle and shell, particularly when the branched nozzles are smaller and have lesser thicknesses.

Nozzle Reinforcing Pads



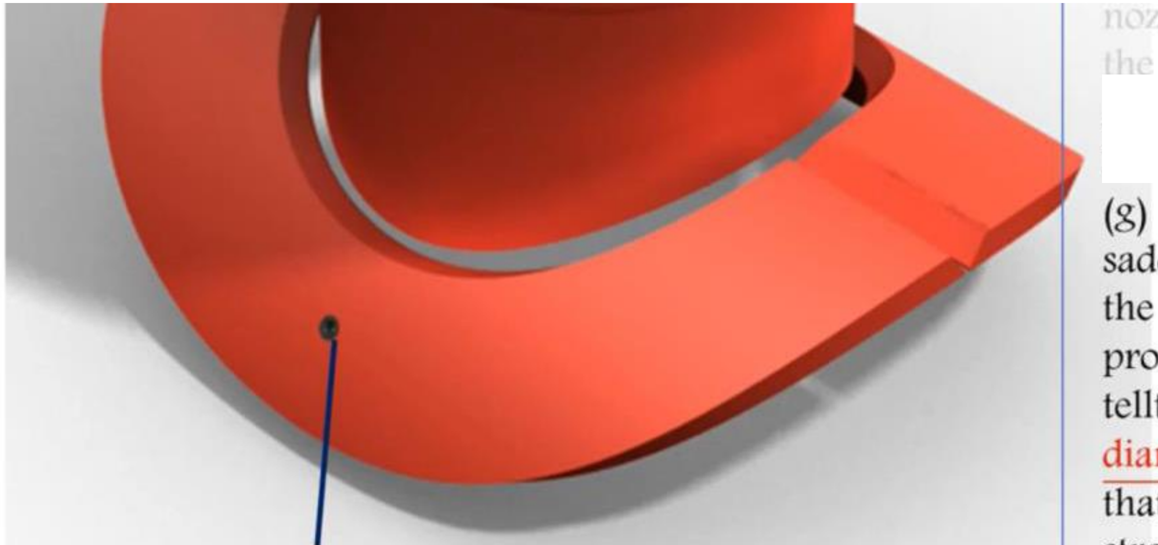
This weakness must be compensated, and can be restored with a Reinforcing Pad, to strengthen the pressure vessel nozzle connection.

Nozzle Reinforcing Pads



a Reinforcing Pad, is a plate formed to the shape "alike donut" that goes around the nozzle joint to add strength to the joint.

nozzle joint to add strength to the joint.



(g) Reinforcing plates and saddles of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole [maximum diameter 7/16 in. (11 mm)] that may be tapped with straight or tapered threads.

Nozzle Reinforcing Pads

Menentukan ukuran nozzle

Ukuran standard nozzle:

- Liquid : $d_i = \pm 2$ inch
- Solid : $d_i = \pm 2$ inch
- Gas : $d_i = < 2$ inch

Metode grafis: penentuan ukuran noozle menggunakan bantuan grafik

Dalam menggunakan grafik, data yang harus diketahui adalah:

- Flowrate
- Jenis aliran
- Densitas dan viskositas bahan

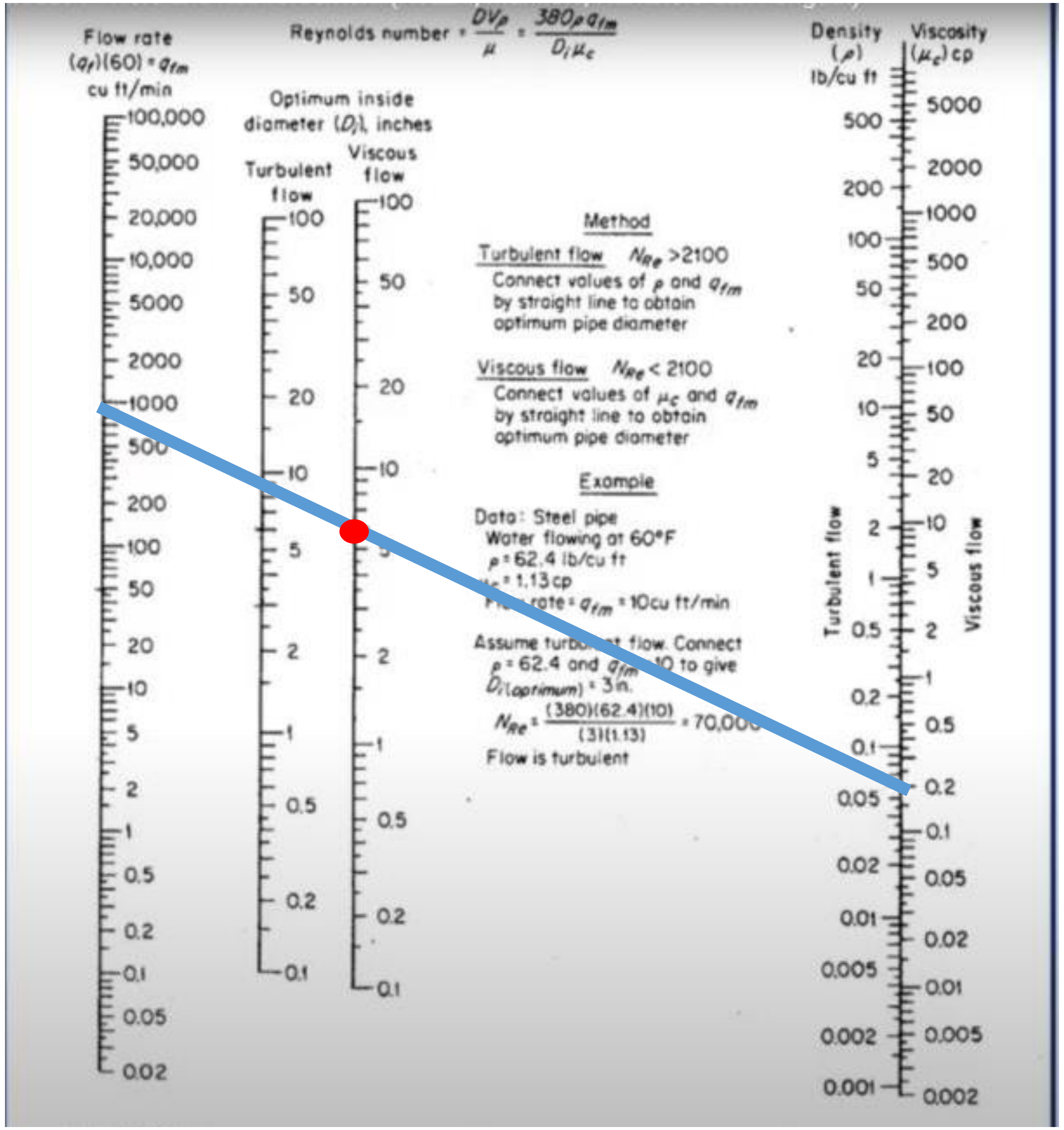
Untuk jenis aliran laminar

Data yang diketahui:

- Flowrate (ft^3/min)
- Viskositas (cp)

Data yang didapatkan:

- Optimum inside diameter (inches)



Menentukan ukuran nozzle

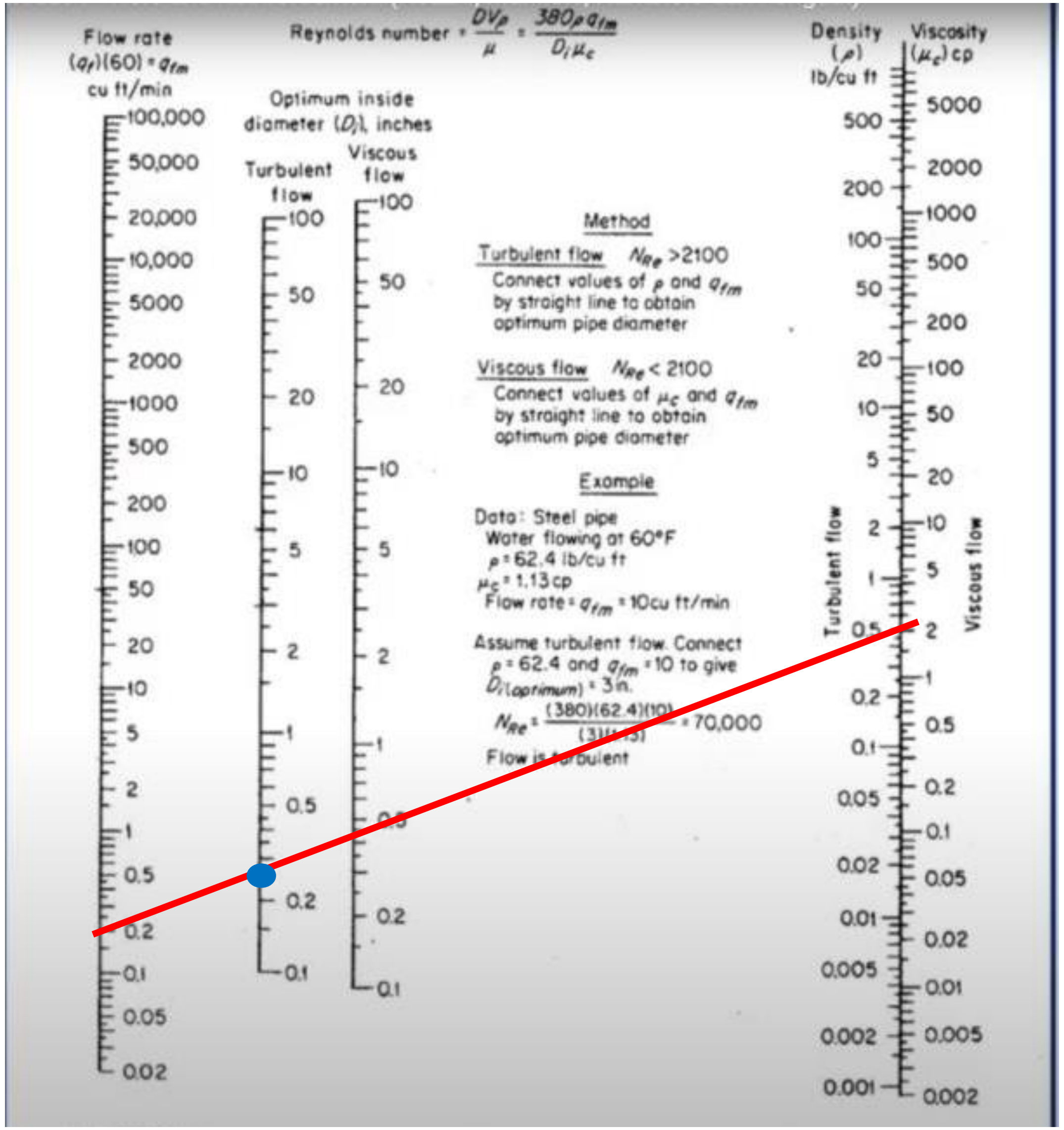
Untuk jenis aliran turbulent

Data yang diketahui:

- Flowrate (ft^3/min)
- Densitas (lb/ft^3)

Data yang didapatkan:

- Optimum inside diameter (inches)



→ Penentuan dioptium pada nozzle juga dapat dicari menggunakan beberapa rumus berikut ini:

Laminar

dipengaruhi oleh viskositas

$N_{Re} < 2100$, $d_i < 0{,}0254$ m → $d_{i\ optimal} = 0{,}133 v^{0,4} \mu\ \rho^{0,2}$

$N_{Re} < 2100$, $d_i < 0{,}0254$ m → $d_{i\ optimal} = 3{,}9 Q^{0,36} \mu^{0,18}$

Turbulent

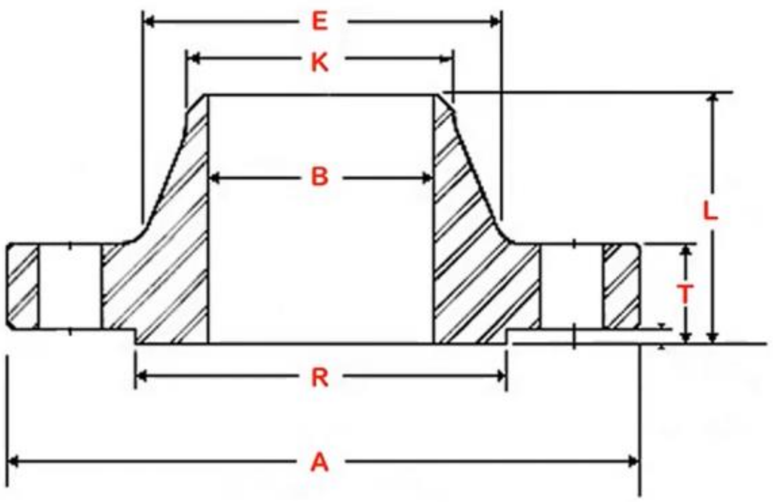
dipengaruhi oleh densitas

$N_{Re} > 2100$, $d_i \geq 0{,}0254$ m → $d_{i\ optimal} = 0{,}363 v^{0,45} \rho^{0,13}$

$N_{Re} > 2100$ → $d_{i\ optimal} = 3{,}9 Q^{0,45} \rho^{0,13}$

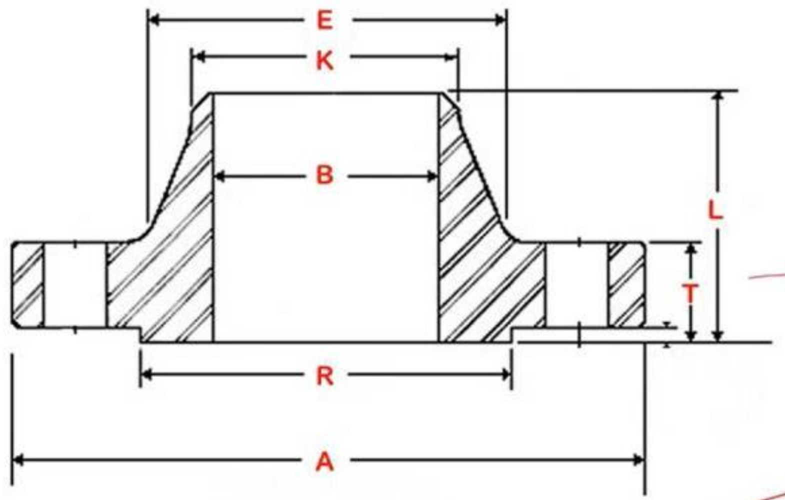
Keterangan:

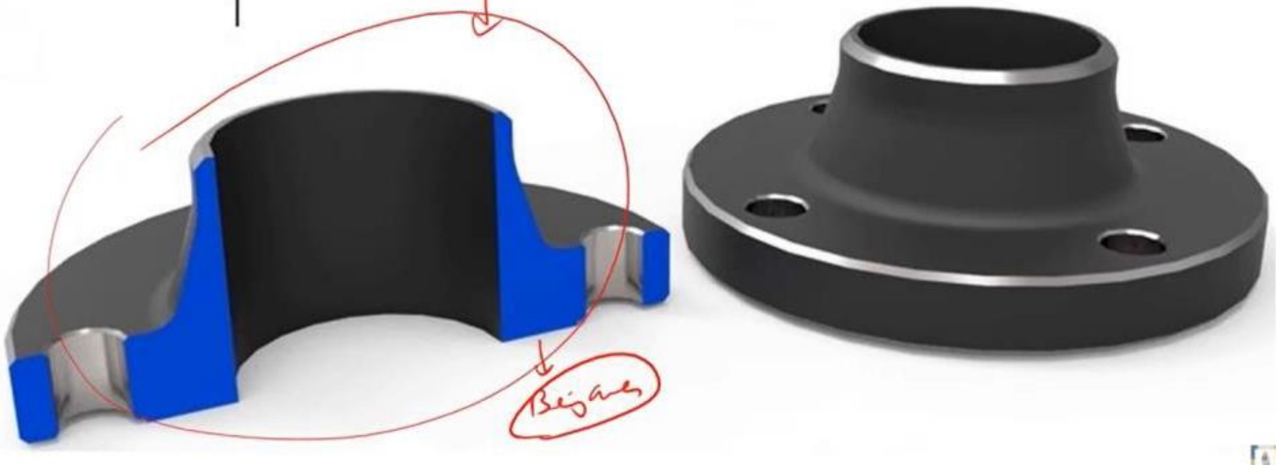
Nre = Reynold number
μ = Viskositas
ρ = Densitas
Q = laju alir volumetrik



Brownell, pg : 221

A = outside diameter of flange
T = thickness of flange
R = outside diameter raised face
E = diameter of hub at base
K = diameter of hub at point of welding
L = length through hub
B = inside diameter of wall pipe


E
K
B
L
T
R
A



Contoh Soal :

Suatu liquid dengan laju alir massa 4202,8832 lb/jam, densitas 65,0748 lb/ft³ dan viskositas 0,000386 lb/ft.det akan dimasukkan ke dalam bejana melalui *nozzle* pemasukan. Desainlah ukuran *nozzle* tersebut!

Diketahui:

$\dot{m} = 4202{,}8832$ lb/jam

$\rho = 65{,}0748$ lb/ft³

$\mu = 0{,}000386$ lb/(ft.detik)

Desain ukuran nozzle :

- **$d_{nominal}$ pipa**
- **di**
- **do**
- **Lebar flange**
- **Tebal flange**
- **Tinggi nozzle**

Penyelesaian :

Asumsi nozzle dibuat dari pipa schedule 40 (sch 40) dan fluida megalir dengan kondisi turbulen, maka :

a. laju alir fluida(Q) $= \frac{m}{\rho} = \frac{4202{,}8832 \frac{lb}{jam}}{65{,}0748 \frac{lb}{ft^3}} \times \frac{1 \text{ jam}}{3600 \text{ detik}} = 0{,}0179 \frac{ft^3}{det}$

b. $d_{i\ optimal} = 3{,}9\ Q^{0{,}45} \rho^{0{,}13} = 3{,}9\ (0{,}0179)^{0{,}45} (65{,}0748)^{0{,}13} = 1{,}0979$ in $= 0{,}0915$ ft (ukuran di distandarisasi menjadi ukuran pipa nominal 1 ¼ in, lihat Brownell pg. 221)

c. *kecepatan alir liquid* $(v) = \frac{Q}{A} = \frac{0{,}0179\ ft^3/det}{(1/4 \pi d_i^2)\ ft^2} = \frac{0{,}0179\ ft^3/det}{(1/4 \pi 0{,}0915^2)\ ft^2} = 2{,}7236\ ft/det$

d. Pengecekan terhadap diameter untuk menghasilkan tipe aliran turbulen, dimana D = d_i = 1,38 in = 0,115 ft

$$N_{Re} = \frac{\rho D v}{\mu} = \frac{(65{,}0748)(0{,}115)(2{,}7236)}{0{,}000386} = 52803.986 > 2100 \rightarrow \text{turbulen}$$

Nominal Pipe Size	Outside Diameter of Flange	Thickness of Flange, Minimum	Outside Diameter of Raised Face	Diameter of Hub at Base	Diameter of Hub at Point of Welding	Length through Hub	Inside Diameter of Standard Wall Pipe
Inches	A	T	R	E	K	L	B
1/2	3 1/2	7/16	1 3/8	1 3/16	0.84	1 7/8	0.62
3/4	3 7/8	1/2	1 11/16	1 1/2	1.05	2 1/16	0.82
1	4 1/4	9/16	2	1 15/16	1.32	2 3/16	1.05
1 1/4	4 5/8	5/8	2 1/2	2 5/16	1.66	2 1/4	1.38
1 1/2	5	11/16	2 7/8	2 9/16	1.90	2 7/16	1.61
2	6	3/4	3 5/8	3 1/16	2.38	2 1/2	2.07
2 1/2	7	7/8	4 1/8	3 9/16	2.88	2 3/4	2.47
3	7 1/2	15/16	5	4 1/4	3.50	2 3/4	3.07
3 1/2	8 1/2	15/16	5 1/2	4 13/16	4.00	2 13/16	3.55
4	9	15/16	6 3/16	5 5/16	4.50	3	4.03
5	10	15/16	7 5/16	6 7/16	5.56	3 1/2	5.05
6	11	1	8 1/2	7 9/16	6.63	3 1/2	6.07
8	13 1/2	1 1/8	10 5/8	9 11/16	8.63	4	7.98
10	16	1 3/16	12 3/4	12	10.75	4	10.02
12	19	1 1/4	15	14 3/8	12.75	4 1/2	12.00
14	21	1 3/8	16 1/4	15 3/4	14.00	5	13.25
16	23 1/2	1 7/16	18 1/2	18	16.00	5	15.25
18	25	1 9/16	21	19 7/8	18.00	5 1/2	17.25
20	27 1/2	1 11/16	23	22	20.00	5 11/16	19.25
24	32	1 7/8	27 1/4	26 1/8	24.00	6	23.25

Maka spesifikasi dari Nozzle adalah :

- $d_{nominal}$ pipa = 1 ¼ inch
- di = 1,38 inch
- do (E) = 2 5/16 inc
- Lebar flange (A) = 4 3/8 inc
- Tebal flange (T) = 5/8 inch
- Tinggi nozzle (L) = 2 ¼ inc

Desain Manhole dan Handhole

Manhole

Diameter 20 in atau 24 in → operator dapat masuk ke dalam bejana untuk memperbaiki atau melakukan perawatan di dalam bejana

Handhole

Tangan operator dapat masuk ke dalam bejana untuk memperbaiki atau melakukan perawatan di dalam bejana

Item 3. Shell-manhole Cover-plate Thickness and Bolting-flange Thickness, Recommended by API Standard 12 C— See Item 4 and Fig. 3.15

(Courtesy of American Petroleum Institute)

Max Tank Height, (ft)	Equivalent Pressure* (psi)	Cover-plate Thickness, Min (in.)		Bolting-flange Thickness after Finishing, Min (in.)	
		20-in. Manhole	24-in. Manhole	20-in. Manhole	24-in. Manhole
20	8.7	5/16	3/8	1/4	1/4
35	15.2	3/8	1/2	1/4	3/8
54	23.4	1/2	5/8	1/8	1/2
79	34.2	5/8	3/4	1/2	5/8

* Based on water loading.

→ **Handhole** memiliki ukuran standar ± 6 inch

Reinforcement/penguat

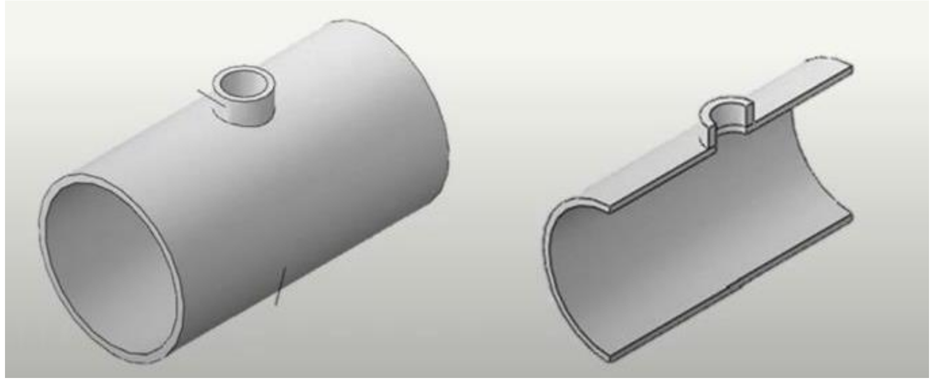
Nozzle / Handhole / Manhole, dibuat dengan melubangi vessel atau bejana atau alat proses

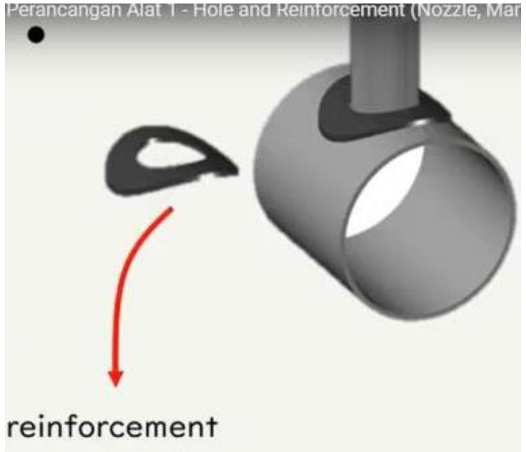
↓

Membuat allowable stress bahan bejana berkurang

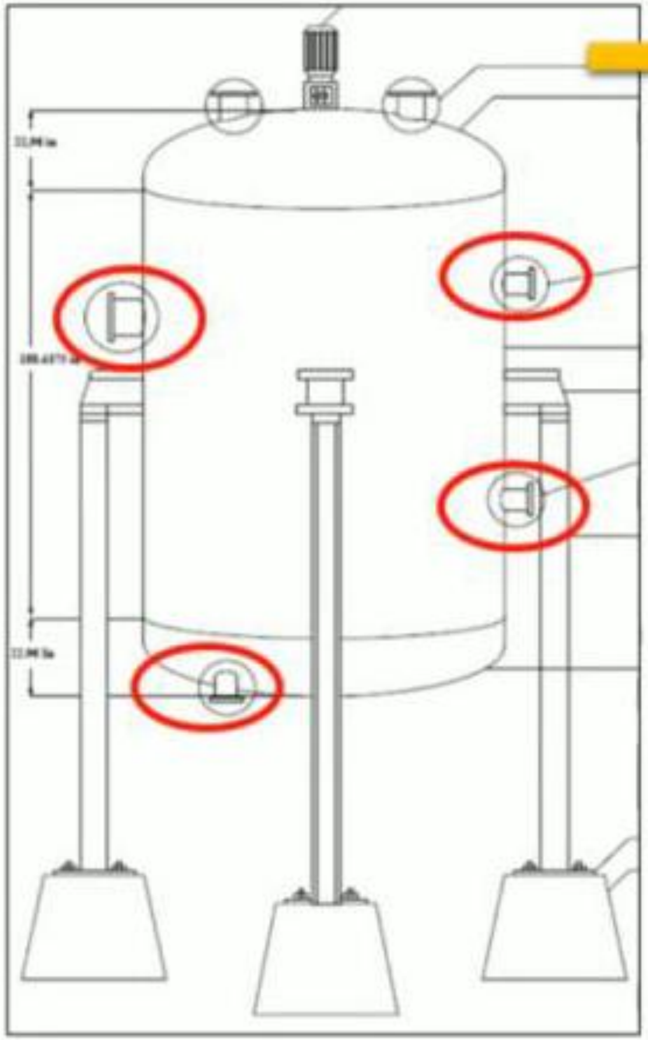
↓

Ditambahkan penguat di sekitar nozzle atau hole yang dibuat





Penguatan Lubang / Reinforcement

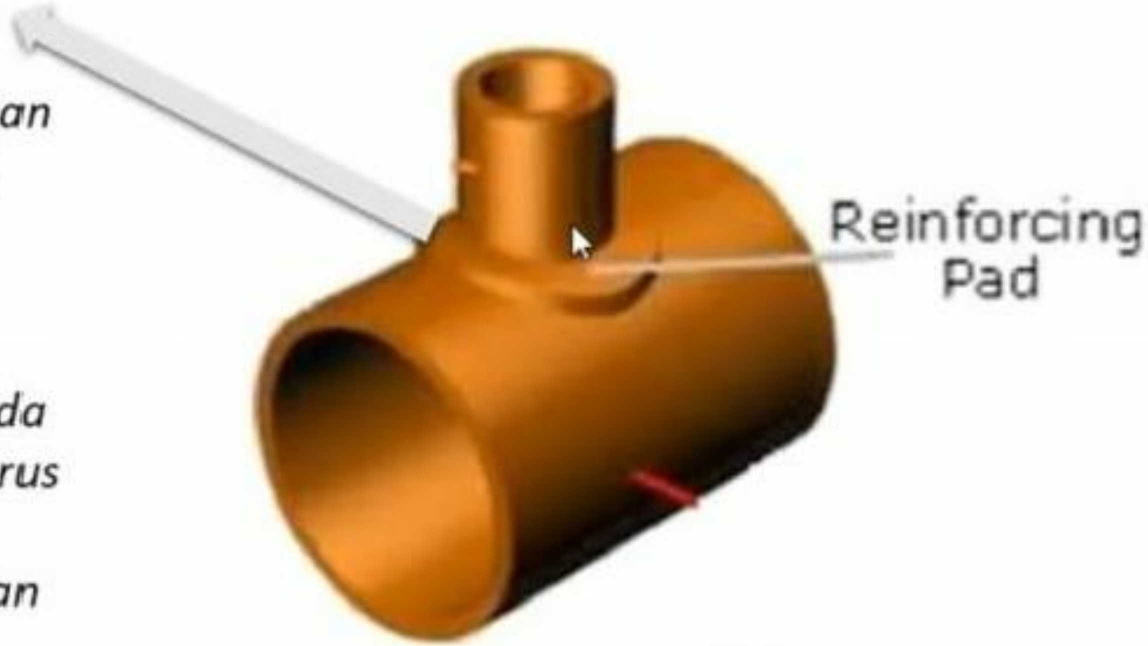


Diameter *dan* ***ketebalan cincin*** *didesain sesuai dengan besarnya penurunan kekuatan bahan.*

Selain tebal dan diameter oenguat, ada dimensi lain yang harus dipenuhi yaitu :

a. Pengelasan bagian dalam (twi)

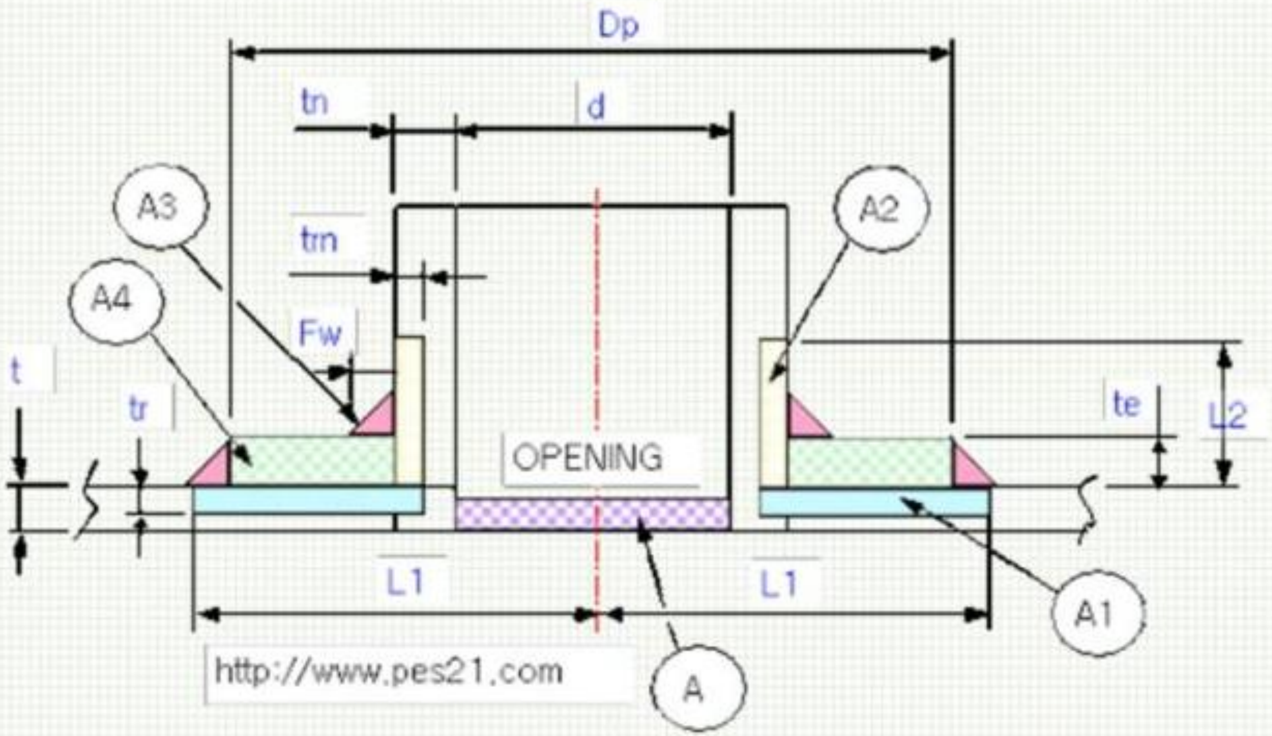
b. Pengelasan bagian luar (two)



$$t_{wi} = 0{,}7 \times t_{min}$$

$$t_{wo} = 0{,}5 \times t_{min}$$

Reinforcement



t_{wo} = *tebal pengelasan bagian luar*
t_{wi} = *tebal pengelasan bagian dalam*
d_n = *diameter nozzle*
d_p = *diameter penguat*
d_{in} = *diameter dalam nozzle*
t_n = *tebal nozzle*
t_p = *tebal penguat*
t_s = *tebal silinder*

Apakah pengelasan sudah memadai?
Apakah perlu penguat atau tidak perlu penguat?
Apakah penguat telah memadai ?

- Dalam penentuan kebutuhan penguat, maka step perhitungan yang dilakukan adalah sebagai berikut:

1. Pengecekan pengelasan

$two_{min} = 0,5\ t_{min}$

$twi_{min} = 0,7\ t_{min}$

Pengelasan memadai jika:

$two > two_{min}$

$twi > twi_{min}$

t_{min} adalah nilai tebal terkecil antara t_s, t_p dan t_n

2. Pengecekan kebutuhan reinforcement

a. Sebelum diberi penguat

$$t_{rs} = \frac{P_i \times d_i}{2(fE - 0{,}6P_i)}$$

$$t_{rn} = \frac{P_i \times d_{in}}{2(fE - 0{,}6P_i)}$$

$A = t_{rs} \times d_{in}$

$A_I = (t_s - t_{rs}) \times d_{in}$

$A_2 = 2[(t_n - t_{rn})(2{,}25t_n + t_p)]$

Jika $A > A_I + A_2$ maka memerlukan penguat

Jika $A < A_I + A_2$ maka tidak memerlukan penguat

Jika di soal dituliskan membutuhkan penguat atau dari hasil perhitungan memerlukan penguat, maka perhitungan dilanjutkan ke point 2b

b. Setelah diberi penguat

Press Esc to exit full screen

$A_3 = t_{wo}^2 + t_{wi}^2$

$A_4 = (d_p - d_{in} - 2t_n) \times t_p$

Evaluasi:

$A < (A_I + A_2 + A_3 + A_4)$ maka penguat memadai

$A > (A_I + A_2 + A_3 + A_4)$ maka penguat tidak memadai

Jika penguat tidak memadai :
Tinjau ulang apakah diameter dan tebal penguat ok, mengganti two dan twi ketentuan untuk menyesuaikan sehingga A < A1 + A2 + A3 + A4

trs = tebal teoritis silinder
trn = tebal teoritis nozzle
(perhitungan reinforcement, diaggap factor korosi adalah 0)

Contoh Soal :

Lakukan pengecekan apakah penguat nozzle berdiameter 18,75 in, tebal ½ in, yang dipasang untuk memperkuat nozzle berdiameter dalam 11,75 in, tebal ½ in, yang dipasang pada bejana berdiameter 60 in, tebal ¾ in. Allowable stress bahan bejana sebesar 14350 psi. Bejana dioperasikan pada tekanan 250 psig. Dan faktor pengelasan dianggap 1 dengan tebal pengelasan bagian luar adalah 7/16 in dan bagian dalam ½ in dengan faktor korosi dianggap nol.

Diketahui : dp = 18,75 in
tp = 0.5 in
dn = 11,75 in
tn = 0.5 in
do = 60 in
ts = 0.75
f = 14350 psi
E = 1
two = 7/16 in
twi = 0.5 in

Penyelesaian :

a. Tentukan tebal teoritis silinder (t_{rs}) dan nozzle (t_{rn})

$$t_{rs} = \frac{P_i \times d_i}{2(fE - 0{,}6P_i)} = \frac{250 \times (60 - (2 \times 0.75))}{2(14350(1) - 0{,}6(250))} = 0.515\ in$$

$$t_{rn} = \frac{P_i \times d_{in}}{2(fE - 0{,}6P_i)} = \frac{250 \times 11{,}75}{2(14350(1) - 0{,}6(250))} = 0{,}103\ in$$

b. Pengecekan tebal pengelasan

$two_{min} = 0{,}5\ t_{min} = 0{,}5 \times 0{,}5 = 0.25\ in$ < 7/16 in

$twi_{min} = 0{,}7\ t_{min} = 0{,}7 \times 0{,}5 = 0.35\ in$ < ½ in

c. Penentuan luas penampang setiap tebal pada bejana dan nozzle

$$A = t_{rs} \times d_{in} = 0{,}515 \times 11{,}75 = 6{,}051\ in^2$$

$$A_1 = (t_s - t_{rs}) \times d_{in} = (0{,}75 - 0{,}515) \times 11{,}75 = 2{,}761\ in^2$$

$$A_2 = 2\left[(t_n - t_{rn})\left(2{,}25t_n + t_p\right)\right] = 2[(0{,}5 - 0{,}103)(2{,}25(0{,}5) + 0{,}5)] = 1{,}287 in^2$$

$$A_3 = t_{wo}^2 + t_{wi}^2 = \left({}^7/_{16}\right)^2 + \left({}^1/_2\right)^2 = 0{,}441 in^2$$

$$A_4 = \left(d_p - d_n - 2t_n\right) \times t_p = (18{,}75 - 11{,}75 - 2(0{,}5)) \times 0{,}5 = 3{,}0 in^2$$

$A < (A_1 + A_2 + A_3 + A_{4)}$

6,051 in^2 < 7,489 in^2

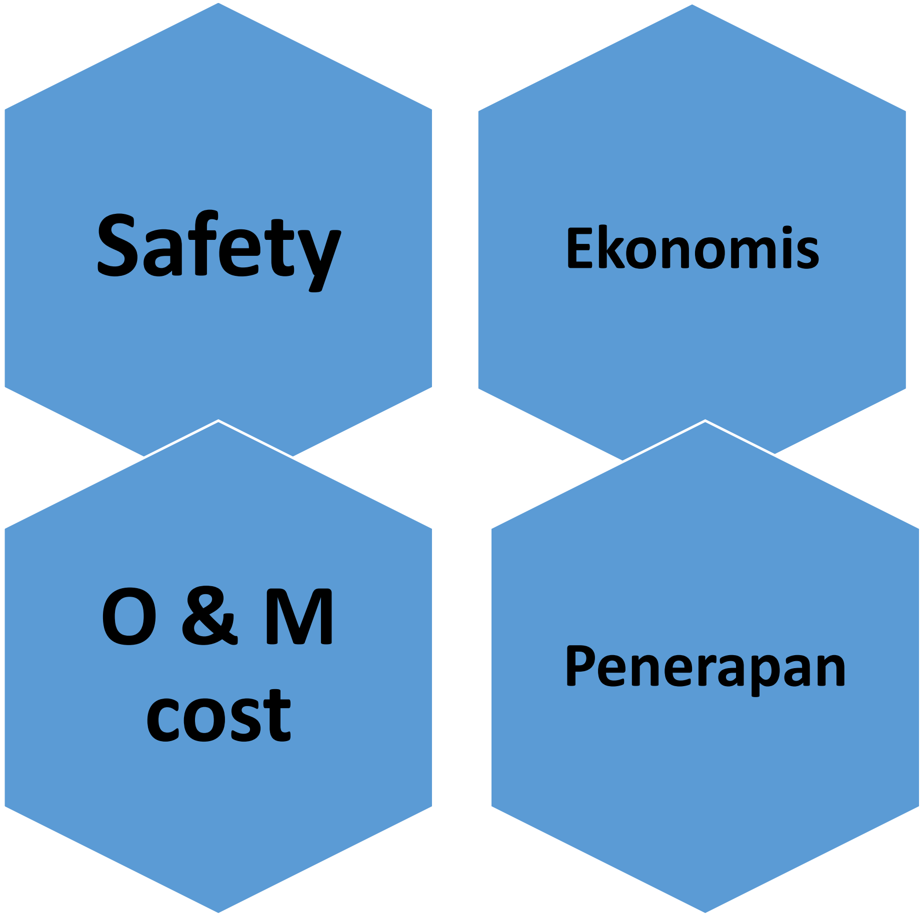
maka penguat memadai

PERANCANGAN ALAT PROSES

“STIFFENER/ Penguat keliling bejana”

Oleh : Indah Prihatiningtyas D.S

PERANCANGAN ALAT PROSES

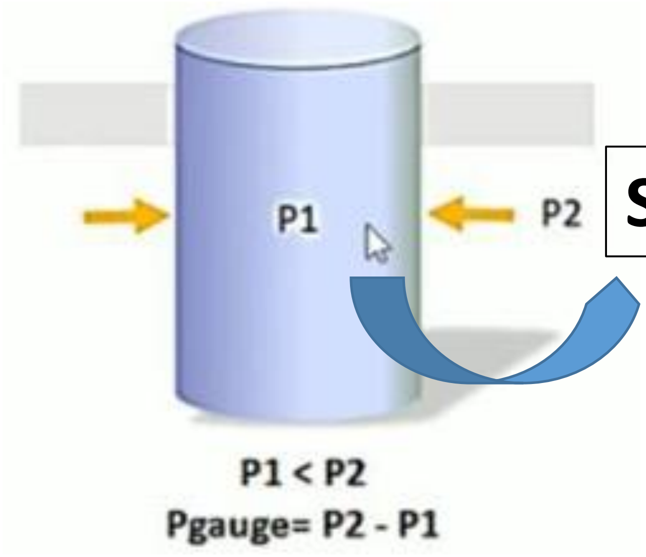


Keselamatan : *Fail safe operation*

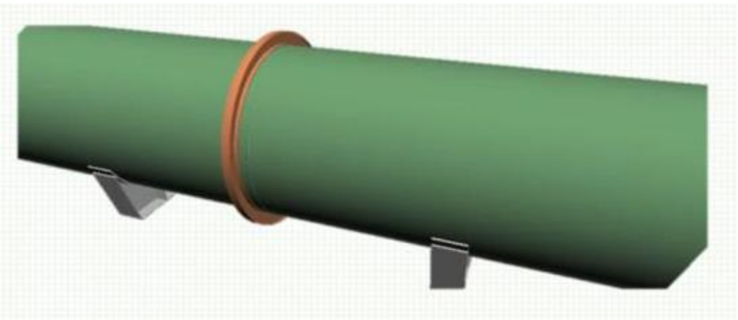
1. Prosedure untuk intervensi operator
2. Indikator parameter proses
3. Kontrol otomatis

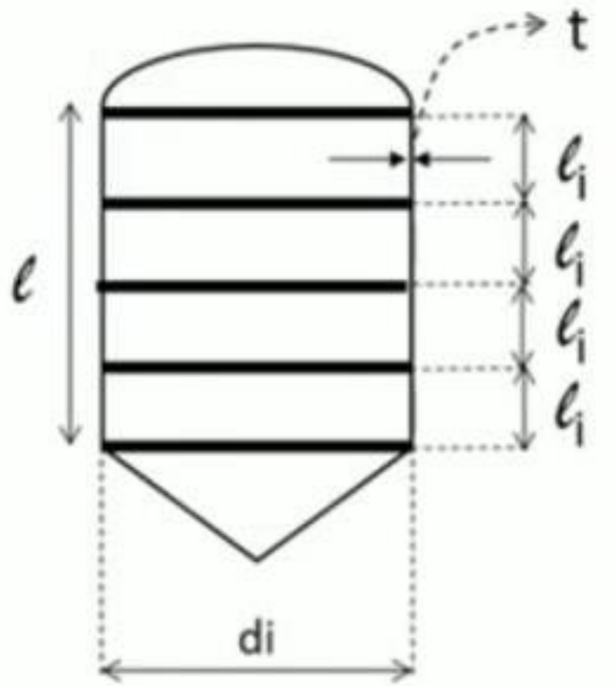
STIFFENER – Penguat keliling

- Eksternal pressure



Silinder Tebal





ℓ_i = jarak antar sabuk

$$\ell_i = \frac{l}{n+1}$$

n = jumlah sabuk

ℓ = tinggi silinder

Stiffener dirancang dengan metode *trial and error*

Tahap perhitungan – (1) trial and error nilai **ts**

1. $l_i = \frac{l}{n+1}$

2. $\frac{l_i}{d_0} = \frac{l_i}{d_i + 2t_s}$

tebak

Hasilnya lebih kecil dari ts awal

3. $\frac{d_o}{t_s} = \frac{d_i + 2\,t_s}{t_s}$

Grafik - Brownell, 147

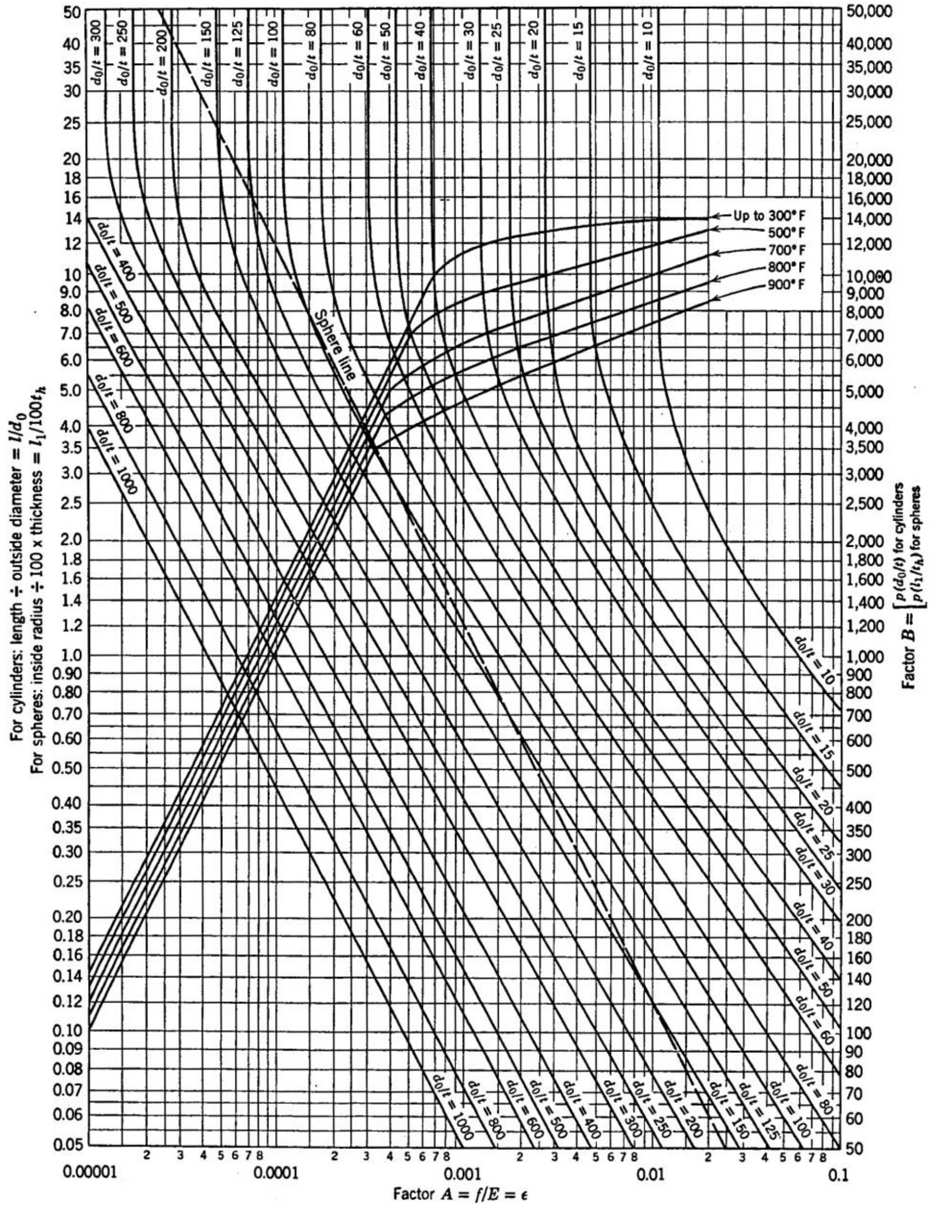
4. $P_{allowable} = \frac{B}{d_o/t_s}$

5. $P_{allowable} > P_{teoritis};\ \Delta P = 10 - 20\%\,;$

$$\Delta P = \frac{P_{allowable} - P_{teoritis}}{P_{teoritis}} \times 100\%$$

Tahapan 1-5 untuk menebak ts setelah diberikan channel/penguat

Grafik - Brownell, 147



Cara mendapatkan B untuk menghitung allowance :

Hitung nilai li/do (dari kiri Tarik ke kanan) ketemukan dengan nilai do/ts. Tarik ke atas sampai ketemu T. Tarik ke kanan untuk dapatkan nilai

Tahap perhitungan – (2) trial and error ukuran channel

Perancangan *channel* didasarkan pada nilai momen inersia (I)

Momen inersia (I)
- I tersedia – Appendix G (Item 1) *(Brownell, 353)*
- I dibutuhkan → $\frac{d_o^2 l_i}{14}\left(t_s + \frac{A_y}{l_i}\right)\varepsilon$

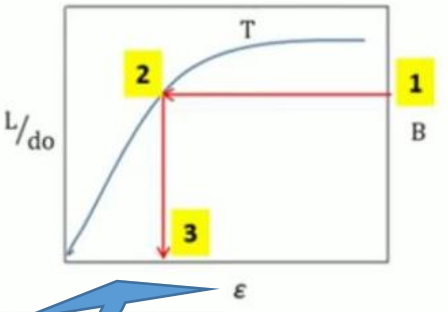
6. Appendiks G, item 1
Perancangan Channel berdasarkan nilai momen inersia (I), yaitu $I_{tersedia}$ dan $I_{dibutuhkan}$
$I_{dibutuhkan} < I_{tersedia}$

7. $I_{dibutuhkan}$ dihitung dengan cara:

$$I_{dibutuhkan} = \frac{d_o^2 l_i}{14}\left(t_s + \frac{A_y}{l_i}\right)\varepsilon$$

Dimana:
$d_o = d_i + 2t_s$
$l_i = jarak\ antara\ sabuk$
$A_y = cross\ sectional\ area$
$\varepsilon = strain\ (garfik\ 8.8)$

Cara mendapat nilai ε dari Grafik 8.8



Tahap perhitungan – (2) trial and error ukuran channel

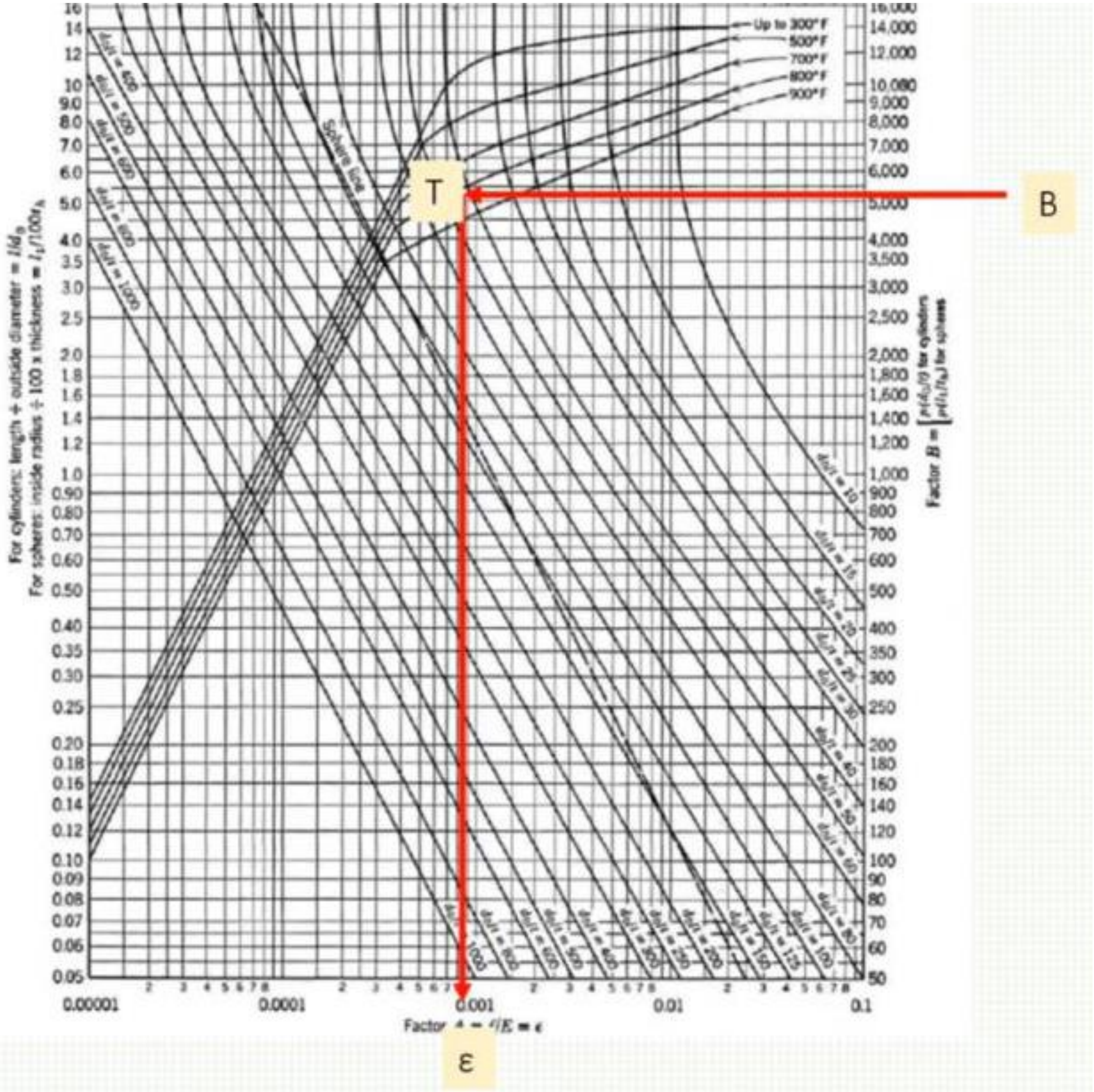
Cara menyelesaikan $I_{dibutuhkan}$:

ε didapatkan dari membaca Grafik 8.8 Halaman 147, untuk membaca ε, harus menghitung B dan mengetahui T

$$B = P_{allow} \times \frac{d_o}{t_s + \frac{A_y}{l_i}}$$

$P_{allow} = hasil\ step\ 4$

Jika nilai B sudah dihitung, cari nilai tersebut di sumbu y (sebelah kanan), kemudia Tarik secara horizontal ke kiri menuju garis Suhu operasi. Titik pertemuan antara B dan T Tarik vertical kebawah menuju sumbu x grafik untuk membaca ε

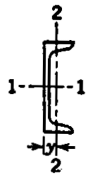


Tahap perhitungan – (2) trial and error ukuran channel

$$I_{dibutuhkan} = \frac{d_o^2 l_i}{14}\left(t_s + \frac{A_y}{l_i}\right)\varepsilon$$

- d_o didapatkan di soal, biasanya diketahui di, lalu cari do nya menggunakan $d_o = d_i + 2t_s$ dengan t_s didapatkan dari trial and error pada section *Stiffener*
- l_i sudah dihitung di STEP 1
- t_s didapatkan dari hasil trial and error STEP 1-5
- A_y didapatkan dengan membaca Appendix G Item 1 dengan trial and error ukuran Channel (cara bacanya di slide setelah ini)
- ε sudah dihitung di slide sebelumnya

8 Setelah menghitung $I_{dibutuhkan}$ bandingkan dengan $I_{tersedia}$. Jika $I_{dibutuhkan} < I_{tersedia}$, maka trial ukuran Channel benar.



A_y

$I_{tersedia}$

Section Index and Nominal Size	Weight per Foot (lb)	Area of Section (in.²)	Depth of Channel (in.)	Width of Flange (in.)	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1–1				Axis 2–2		
							I (in.⁴)	S (in.³)	r (in.)	I (in.⁴)	S (in.³)	r (in.)	y (in.)
C 60	58.0	16.98		4.200	0.625	0.700	670.7	74.5	6.29	18.5	5.6	1.04	0.88
18 x 4	51.9	15.18	18	4.100	0.625	0.600	622.1	69.1	6.40	17.1	5.3	1.06	0.87
R = 0.625	45.8	13.38		4.000	0.625	0.500	573.5	63.7	6.55	15.8	5.1	1.09	0.89
	42.7	12.48		3.950	0.625	0.450	549.2	61.0	6.64	15.0	4.9	1.10	0.90
C 1	50.0	14.64		3.716	0.650	0.716	401.4	53.6	5.24	11.2	3.8	0.87	0.80
15 x 3⅜	40.0	11.70	15	3.520	0.650	0.520	346.3	46.2	5.44	9.3	3.4	0.89	0.78
R = 0.50	33.9	9.90		3.400	0.650	0.400	312.6	41.7	5.62	8.2	3.2	0.91	0.79
C 20	50.0	14.66		4.412	0.610	0.787	312.9	48.1	4.62	16.7	4.9	1.07	0.98
13 x 4	40.0	11.71	13	4.185	0.610	0.560	271.4	41.7	4.82	13.9	4.3	1.09	0.97
R = 0.48	35.0	10.24		4.072	0.610	0.447	250.7	38.6	4.95	12.5	4.0	1.10	0.99
	31.8	9.30		4.000	0.610	0.375	237.5	36.5	5.05	11.6	3.9	1.11	1.01
C 2	30.0	8.79		3.170	0.501	0.510	161.2	26.9	4.28	5.2	2.1	0.77	0.68
12 x 3	25.0	7.32	12	3.047	0.501	0.387	143.5	23.9	4.43	4.5	1.9	0.79	0.68
R = 0.38	20.7	6.03		2.940	0.501	0.280	128.1	21.4	4.61	3.9	1.7	0.81	0.70
C 3	30.0	8.80		3.033	0.436	0.673	103.0	20.6	3.42	4.0	1.7	0.67	0.65
10 x 2⅝	25.0	7.33	10	2.886	0.436	0.526	90.7	18.1	3.52	3.4	1.5	0.68	0.62
R = 0.34	20.0	5.86		2.739	0.436	0.379	78.5	15.7	3.66	2.8	1.3	0.70	0.61
	15.3	4.47		2.600	0.436	0.240	66.9	13.4	3.87	2.3	1.2	0.72	0.64
C 4	20.0	5.86		2.648	0.413	0.448	60.6	13.5	3.22	2.4	1.2	0.65	0.59
9 x 2½	15.0	4.39	9	2.485	0.413	0.285	50.7	11.3	3.40	1.9	1.0	0.67	0.59
R = 0.33	13.4	3.89		2.430	0.413	0.230	47.3	10.5	3.49	1.8	0.97	0.67	0.61
C 5	18.75	5.49		2.527	0.390	0.487	43.7	10.9	2.82	2.00	1.00	0.60	0.57
8 x 2¼	13.75	4.02	8	2.343	0.390	0.303	35.8	9.0	2.99	1.50	0.86	0.62	0.56
R = 0.32	11.50	3.36		2.260	0.390	0.220	32.3	8.1	3.10	1.30	0.79	0.63	0.58

Kode Channel

Ukuran Channel

Item 1. Channels, American Standard, Properties of Sections (Continued)

Section Index and Nominal Size	Weight per Foot (lb)	Area of Section (in.²)	Depth of Channel (in.)	Width of Flange (in.)	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1–1			Axis 2–2			
							I (in.⁴)	S (in.³)	r (in.)	I (in.⁴)	S (in.³)	r (in.)	y (in.)
C 6	14.75	4.32		2.299	0.366	0.419	27.1	7.7	2.51	1.40	0.79	0.57	0.53
7 x 2⅛	12.25	3.58	7	2.194	0.366	0.314	24.1	6.9	2.59	1.20	0.71	0.58	0.53
R = 0.31	9.80	2.85		2.090	0.366	0.2.0	21.1	6.0	2.72	0.98	0.63	0.59	0.55
C 7	13.00	3.81		2.157	0.343	0.437	17.3	5.8	2.13	1.10	0.65	0.53	0.52
6 x 2	10.50	3.07	6	2.034	0.343	0.314	15.1	5.0	2.22	0.87	0.57	0.53	0.50
R = 0.30	8.20	2.39		1.920	0.343	0.200	13.0	4.3	2.34	0.70	0.50	0.54	0.52
C 8 5 x 1¾	9.00	2.63	5	1.885	0.320	0.325	8.8	3.5	1.83	0.64	0.45	0.49	0.48
R = 0.29	6.70	1.95		1.750	0.320	0.190	7.4	3.0	1.95	0.48	0.38	0.50	0.49
C 9 4 x 1⅝	7.25	2.12	4	1.720	0.296	0.320	4.5	2.3	1.47	0.44	0.35	0.46	0.46
R = 0.28	5.40	1.56		1.580	0.296	0.180	3.8	1.9	1.56	0.32	0.29	0.45	0.46
C 10	6.00	1.75		1.596	0.273	0.356	2.1	1.4	1.08	0.31	0.27	0.42	0.46
3 x 1½	5.00	1.46	3	1.498	0.273	0.258	1.8	1.2	1.12	0.25	0.24	0.41	0.44
R = 0.27	4.10	1.19		1.410	0.273		1.6	1.1	1.17	0.20	0.21	0.41	0.44

CONTOH SOAL :

Suatu bejana bertekanan vacuum dibawah tekanan atmosferik memiliki diameter 14 ft dan tinggi bagian silindernya 21 ft serta tebal awalnya pada bagian silinder adalah sebesar 5/8 in. Bejana dioperasikan pada suhu 750 oF dan diberi sabuk pengaman setiao 39 in dengan berat 12.25 lb/ft. Berapa tebal bagian silender setelah diberikan pengaman dan apakah sabuk pengaman tersebut memnuhi syarat ?

Diket :

di= 14 ft

l= 21 ft

ts awal = 5/8 in

T = 750 oC

li = 39 in

Kedalaman channel 7 in

Berat 12.25 lb/ft

PERANCANGAN ALAT PROSES

“Support and design of support”

Oleh : Indah Prihatiningtyas D.S

Support to Vessels

Design of vessel cannot be completed without selection and design of a suitable support for it, and also without examining the effect of support on shell.

Vessels such as distillation column, absorption column and evaporator, stirred tank reactor are supported in vertical position.

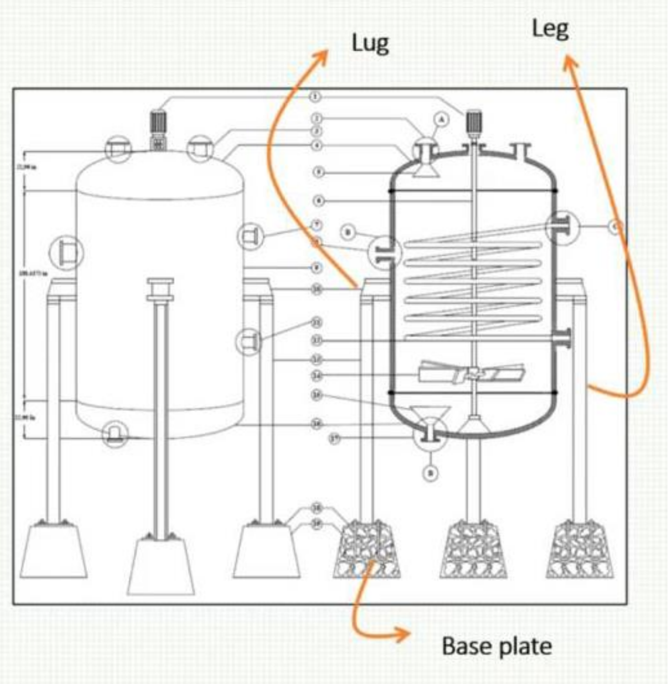
Horizontal placed vessels are heat exchanger, condenser, etc.

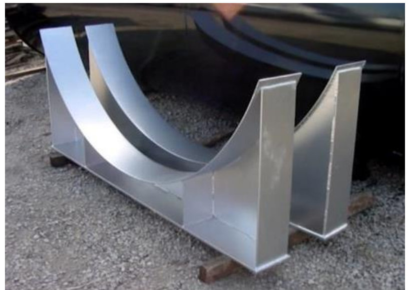
Vertical vessel

1. Skirt support
2. Bracket or lug support
3. Leg support

Horizontal vessel

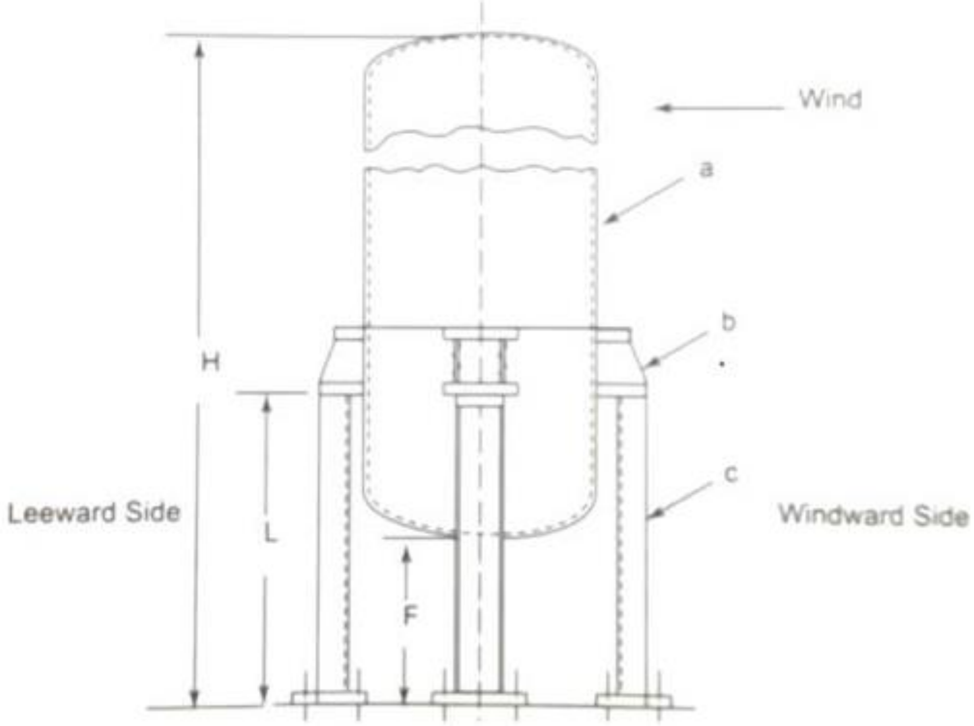
1. Saddle support
2. Leg support





Bracket or lug support

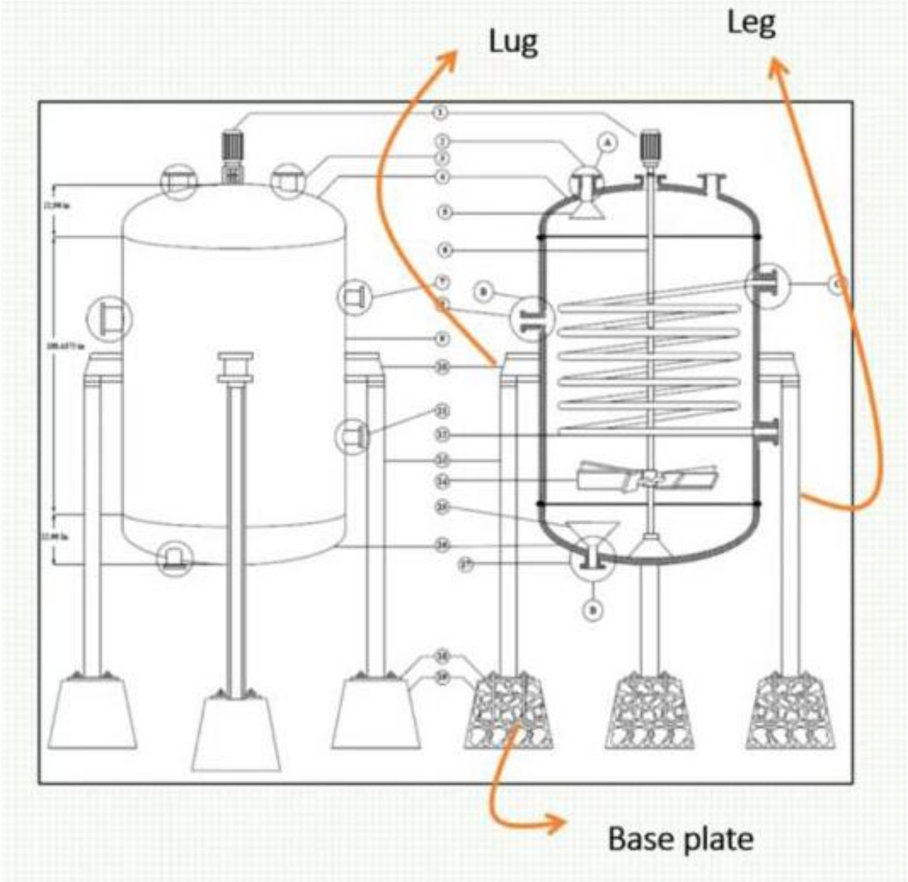
The main loads on the bracket supports are dead weight of the vessel with its contents and the wind load. The wind load tends to overturn the vessel, particularly when it is empty.



These are used to support vertical vessels of smaller height (subjected to minor wind loads). These can be easily fabricated from plates and attached to the vessel wall with a minimum welding length. These are made on rest on short columns or on beams of a structure depending on the elevation required.

The main loads on the bracket supports are dead weight of the vessel with its contents and the wind load. The wind load tends to overturn the vessel, particularly when it is empty.

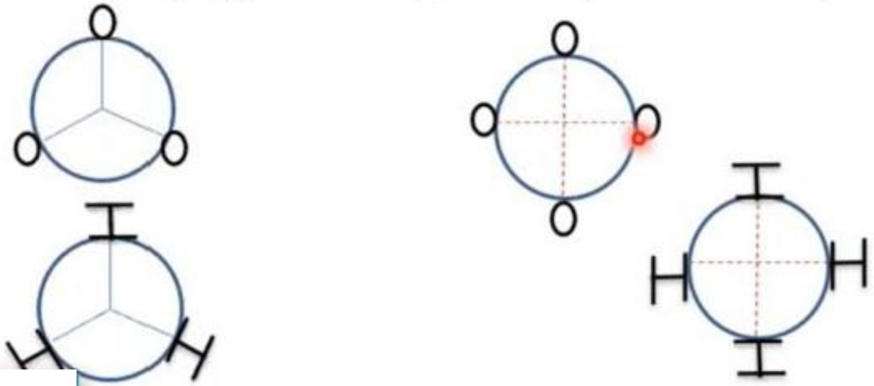
The maximum compressive stresses in the supports occur on the leeward side when the vessel is full, since dead load and wind load have a similar effect.
The maximum tensile stresses are set up to the wind side when the vessel is empty, since dead load and wind load have opposing effects.



Leg adalah bagian kaki penyangga

Dibuat dari : Pipa I,r
I Beam sumbu I,1 –1, r 1-1
sumbu I,2-2 , r2-2

Jumlah penyangga : 3 atau 4 (pertimbangan ekonomis : 3)



Jumlah leg berpengaruh pada besar beban yang akan ditahan oleh masing – masing Leg.

Vertical vessel

DESAIN PENYANGGA (LEG)

a. Jumlah *Leg*

Jumlah *leg* berpengaruh pada besar beban yang akan ditahan oleh masing – masing *leg* dimana besar beban yang akan ditahan oleh masing – masing *leg* (P)

The maximum compression load on each lug:

$$P = \frac{4P_w(H - H_c)}{nC} + \frac{W_{max}}{n}$$

Bejana Pendek → Pw diabaikan $P = \frac{\Sigma W}{n}$

Tekanan angin bejana pendek didalam ruangan dapat diabaikan. Sehingga besar beban menjadi:

P = maximum compression load per lug

P_w = total force due to wind load $P_w = K_1 K_2 p_1 h_1 D_o$

K_1 = 0.7 (for cylinder)

K_2 = 1 (as period of vibrations are usually very small < 0.5 s)

H = height of vessel above foundation

H_c = vessel clearance from foundation to vessel bottom **$H - H_c$ = ht. of vessel**

C = diameter of anchor bolt circle

W_{max} = maximum weight of vessel with attachments

n = no. of lugs

Wind load can be neglected if the vessel is indoors

b. **Tinggi *Leg (l)***

Tinggi *leg* didasarkan pada tinggi bejana yang terdiri dari :

✓ Tinggi total bejana (H), yaitu bagian tutup bawah, bagian silinder, dan tutup atas

✓ Tinggi ujung tutup bawah ke permukaan tanah (L), umumnya diasumsikan sebesar 5 ft

- Tinggi leg dapat ditentukan berdasarkan

$$l = L + h = 5ft + 0,5 * (hb + Ls + Sf + ha)$$

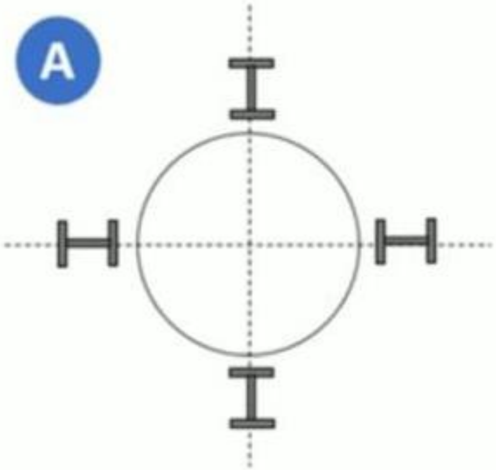
- L adalah jarak permukaan tanah ke ujung bawah tangki, biasanya 5 ft.

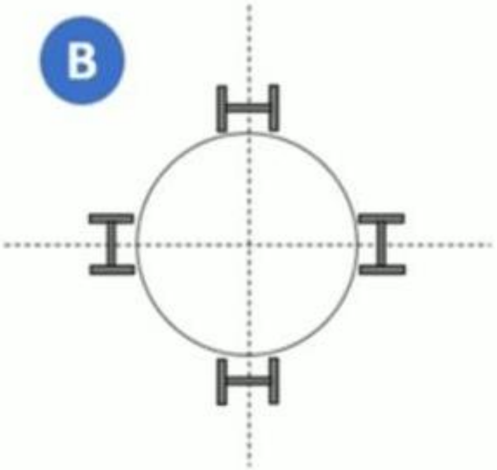
- Seperti mendesain channel sabuk pengaman, dilakukan trial ukuran Leg dan menetapkan harga stress compressive (fc) aman

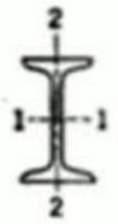
Ukuran *leg* ditentukan dengan cara *trial* dan menetapkan harga *stress compressive* (fc) aman pada *leg* dengan berdasarkan pada peletakan *leg* tersebut. Peletakan pada bejana dengan memperhatikan penampang *leg*. Penampang *leg* terdiri dari 2 macam, yaitu :

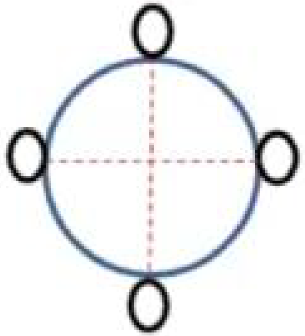
✓ Tanpa beban konsentris (A)
  Peletakan *leg* tanpa beban konsentris biasa digunakan untuk *leg* tipe *I Beam* dan tipe pipa

✓ Dengan beban konsentris (B)
  Peletakan *leg* dengan beban konsentris biasa digunakan juga untuk tipe *I Beam*









DESAIN PENYANGGA (LEG)

Tahapan desain *leg :*

1. Tetapkan harga fc aman. Nilai fc tergantung tata letak *I Beam*
   - ✓ Tanpa beban konsentris

$$fc = \frac{18000}{1 + \frac{l^2}{18000r^2}}$$

$$fc_{aman} = fc = P/A$$

   - ✓ Dengan beban konsentris
     - l/r=0-60 → fc = 15000 psi
     - l/r=61-200 → $fc = \frac{18000}{1+\frac{l^2}{18000r^2}}$
     - $fc_{aman} = fc - fc_{konsentris}$, dimana $fc_{konsentris} = \frac{P(a+\frac{1}{2}b)}{I/\frac{1}{2}b}$
2. Evaluasi nilai luas penampang *leg* (A)

$A = \frac{P}{fc_{aman}}$ → memadai jika A>A tersedia

NOTE :
fc = stress compressive
a = jarak dari pusat *leg* ke dinding silinder (umumnya dipakai 1,5 in)
b = *width of flange*

- Cek Nilai A hitung:

$$A = \frac{P}{fc\ aman}$$

- Pastikan dapat terpenuhi oleh A tersedia di Tabel App. G

A tersedia b h

Properties of Selected Rolled Structural Members 355

Item 2. Beams, American Standard, Properties of Sections (Continued)

Section Index and Nominal Size	Weight per Foot (lbs)	Area of Section (in.²)	Depth of Beam (in.)	Width of Flange (in.)	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1-1 I (in.⁴)	Axis 1-1 S (in.³)	Axis 1-1 r (in.)	Axis 2-2 I (in.⁴)	Axis 2-2 S (in.³)	Axis 2-2 r (in.)
12" I B 8 12 x 5¼ R = 0.56	50.0	14.57	12	5.477	0.659	0.687	301.6	50.3	4.55	16.0	5.8	1.05
	40.8	11.84		5.250	0.659	0.460	268.9	44.8	4.77	13.8	5.3	1.08
12" I B 9 12 x 5 T = 0.45	35.0	10.20	12	5.078	0.544	0.428	227.0	37.8	4.72	10.0	3.9	0.99
	31.8	9.26		5.000	0.544	0.350	215.8	36.0	4.83	9.5	3.8	1.01
10" I B 10	35.0	10.22	10	4.944	0.491	0.594	145.8	29.2	3.78	8.5	3.4	0.91

Contoh design penyangga Leg

Suatu bejana dengan berat total beserta isinya 35000 lb dan berat tutup atas dan bawah sebesar 1800 lb, akan dipasang penyangga tipe Leg dengan bentuk I Beam. Tinggi total bejana 10 ft dan diameter bejana 6,5 ft. Apabila jumlah penyangga yang digunakan sebanyak 4 buah dengan ukuran 12 in, berat 50 lb/ft, Apakah penyangga tersebut sudah memadai?

Bandingkan leg tanpa beban konsentris dan dengan beban konsentris

Jawaban :

Diketahui : $\sum W$ = 35000 + 1800 lb = 36800 lb

jenis Leg = I Beam

jumlah penyangga (n) = 4 buah

ukuran nominal I Beam = 12 in, 50 lg/ft

Tinggi total bejana (Ls + ha + hb + Sf) = 10 ft

D bejana = 6,5 ft

*Tanpa Beban Konsentris

1. Mencari beban tiap penyangga : $P = \frac{\sum W}{n} = \frac{36800}{4} = 9200\ lb$

2. Mencari tinggi Leg (*l*) = 5 ft + ½ (Ls + ha + hb + Sf) = 5ft + ½ (10 ft) = 10 ft = 120 in

3. dengan tanpa beban konsentris, maka dalam melihat tabel mengikuti yang 2-2

Section Index and Nominal Size	Weight per Foot (lbs)	Area of Section (in.²)	Depth of Beam (in.)	Width of Flange (in.)	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1-1			Axis 2-2		
							I (in.⁴)	S (in.³)	r (in.)	I (in.⁴)	S (in.³)	r (in.)
12″ I B 8	50.0	14.57	12	5.477	0.659	0.687	301.6	50.3	4.55	16.0	5.8	1.05
12 x 5¼	40.8	11.84		5.250	0.659	0.460	268.9	44.8	4.77	13.8	5.3	1.08
R = 0.56												
12″ I B 9	35.0	10.20	12	5.078	0.544	0.428	227.0	37.8	4.72	10.0	3.9	0.99
12 x 5	31.8	9.26		5.000	0.544	0.350	215.8	36.0	4.83	9.5	3.8	1.01
T = 0.45												

Dari table didapatkan :

A tersedia = 14.57 in2 **B = 5.477**

$I_{2\text{-}2}$ = 16 in^4 **$R_{2\text{-}2}$ + 1.05 in**

4. Tanpa beban konsentris maka fc – fcaman.

$$fc = \frac{18000}{l + \frac{l^2}{18000 r^2}} = \frac{18000}{120 + \frac{120^2}{18000(1{,}05)^2}} = 10430{,}68 \frac{lb}{in2}$$

Fc = fcaman = 10430,68 lb/in2

5. Mencari A hitung :

$A = \frac{9200}{10430.68} = 0.88\ in^2$

6. Mambandingkan A tersedia dengan A hitung

A tersedia (14.57) > A hitung (0.88)

7. Menyimpulkan bahwa leg dengan tanpa beban konsentris dengan ukuran nominal I Beam telah memadai.

*Dengan Beban Konsentris

1. Mencari beban tiap penyangga : $P = \frac{\sum W}{n} = \frac{36800}{4} = 9200\ lb$

2. Mencari tinggi Leg (*l*) = 5 ft + ½ (Ls + ha + hb + Sf) = 5ft + ½ (10 ft) = 10 ft = 120 in

3. dengan tanpa beban konsentris, maka dalam melihat tabel mengikuti yang 1-1

Section Index and Nominal Size	Weight per Foot (lbs)	Area of Section (in.²)	Depth of Beam (in.)	Width of Flange (in.)	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1-1			Axis 2-2		
							I (in.⁴)	S (in.³)	r (in.)	I (in.⁴)	S (in.³)	r (in.)
12" I												
B 8	50.0	14.57	12	5.477	0.659	0.687	301.6	50.3	4.55	16.0	5.8	1.05
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R = 0.56												
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B 9	35.0	10.20	12	5.078	0.544	0.428	227.0	37.8	4.72	10.0	3.9	0.99
12 x 5	31.8	9.26		5.000	0.544	0.350	215.8	36.0	4.83	9.5	3.8	1.01
T = 0.45												

Dari table didapatkan :

A tersedia = 14.57 in2   **b = 5.477**

I_{1-1} = 301.6 in^4   **r_{1-1} = 4.5 in**

4. Mencari l/r = 120 in/4.5 = 26.37

5. Karena nilai l/r (0-60), maka mencari nilai fc (stress compressive) dengan :

fc = 15000 psi

6. Mencari fcaman :

- $fc_{aman} = fc - fc_{konsentris}$, dimana $fc_{konsentris} = \frac{P(a+\frac{1}{2}b)}{I/\frac{1}{2}b}$

$fc_{konsentris} = \frac{P(a+\frac{1}{2}b)}{\frac{I}{\frac{1}{2}b}} = \frac{9200(1.5+\frac{1}{2}5.477)}{\frac{301.6}{\frac{1}{2}5.477}} = 354.06$

fc_{aman} = 15000-354.06 = 14645.94

7. Mencari A hitung :

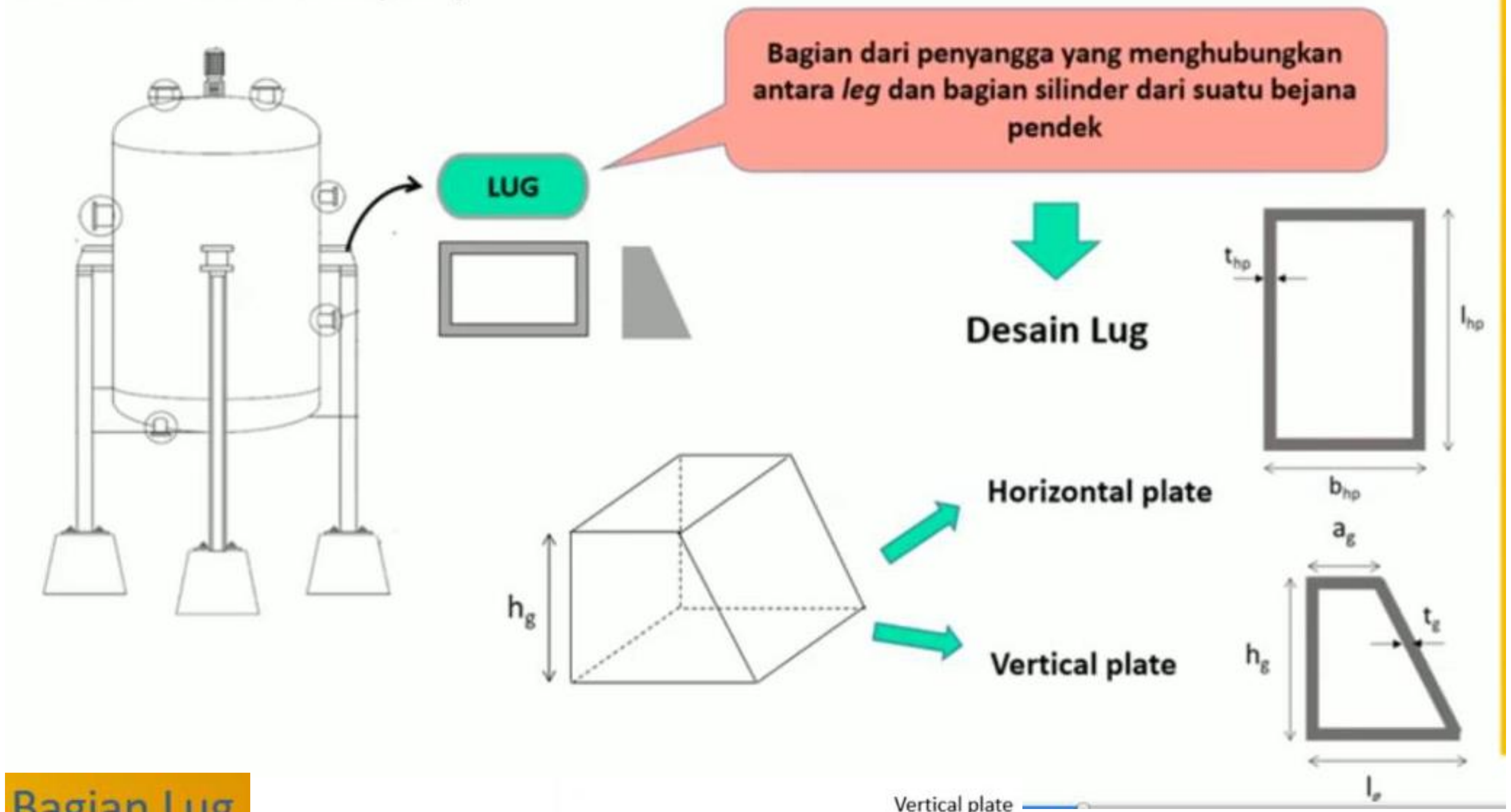
$A = \frac{9200}{14645.94} = 0.628$ in^2

8. Mambandingkan A tersedia dengan A hitung

A tersedia (14.57) > A hitung (0.628)

9. Menyimpulkan bahwa leg dengan beban konsentris dengan ukuran nominal I Beam telah memadai.

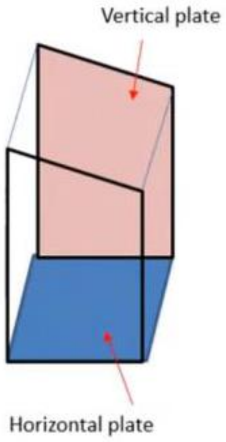
DESAIN PENYANGGA (LUG)



Bagian Lug

Bagian horizontal

Bagian Vertical



Desain Lug bagian Horizontal Plate

Tipe leg I beam

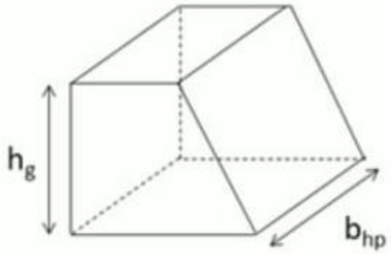
Membutuhkan spesifikasi:
- Panjang plate (l_{hp})
- Lebar (b_{hp})
- Tebal (t_{hp})

Yang bergantung ukuran leg

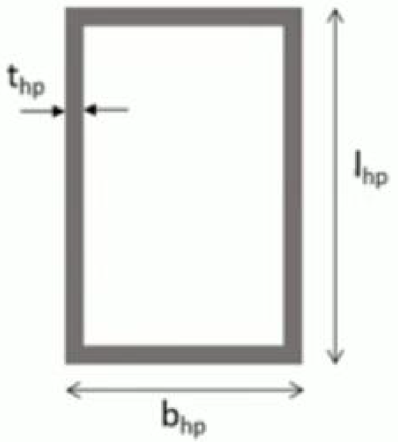
Tipe leg Pipe

Membutuhkan spesifikasi:
- Panjang plate (l_{hp})
- Lebar (b_{hp})
- Tebal (t_{hp})

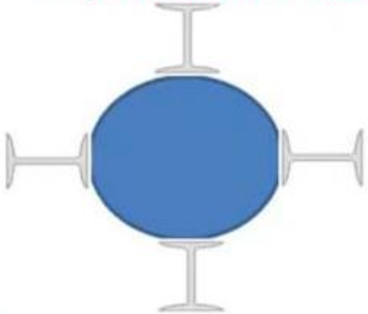
Yang nilai (l_{hp}) = (b_{hp})



Horizontal Plate
- Panjang (l_{hp})
- Lebar (b_{hp})
- Tebal (t_{hp})
- Untuk *leg* tipe pipa $b_{hp} = l_{hp}$
- Untuk *leg* tipe I Beam → tanpa/dengan beban konsentris

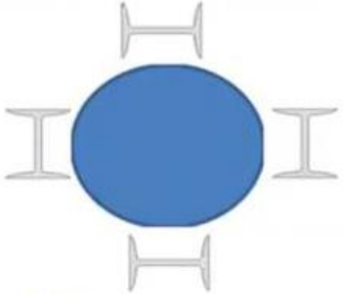


Tanpa Beban Konsentris



- Lebar
  - (b_{hp}) = b_{Ibeam} + 2 x d_{baut}
- Panjang plate
  - (l_{hp}) = h_{Ibeam} + 2 x d_{baut}

Dengan Beban Konsentris



- Lebar
  - (b_{hp}) = h_{Ibeam} + 2 x d_{baut}
- Panjang plate
  - (l_{hp}) = b_{Ibeam} + 1,5 in + 2 xd_{baut}

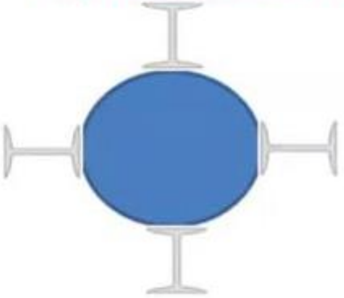
- Tebal $thp = \sqrt{\frac{6\,M}{fallowable}}$, fallowable = 12000, μ = 0,33
- Dimana $M = \frac{\beta^3 t_s^2 PC(\frac{1}{2}d)^2}{12(1-\mu^2)b.h}$ dan $\beta = \sqrt{\frac{3(1-\mu^2)}{t_s^2(\frac{1}{2}d)^2}}$

Vertical Plate Lug dengan leg I beam

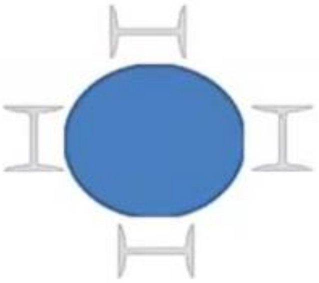
Vertical plate adalah bagian dari lug yang menghubungkan horizontal plate bagian atas dan bagian bawah yang disebut ***gusset***

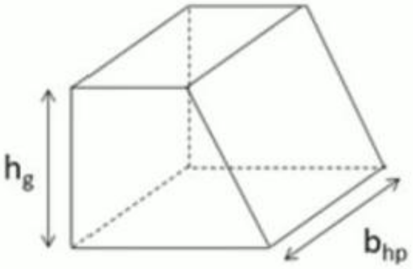
Gusset terdiri dari : *sisi bagian bawah (lg), sisi bagian atas (ag), tinggi (hg), dan tebal (tg)*

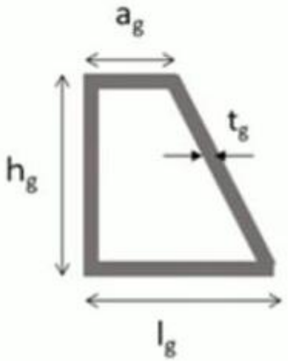
Tanpa Beban Konsentris



Dengan Beban Konsentris







Vertical Plate (*Gusset*)

- Sisi bagian bawah (l_g)
- Sisi bagian atas (a_g)
- Tinggi (h_g)
- Tebal (t_g)

Untuk leg tipe I Beam

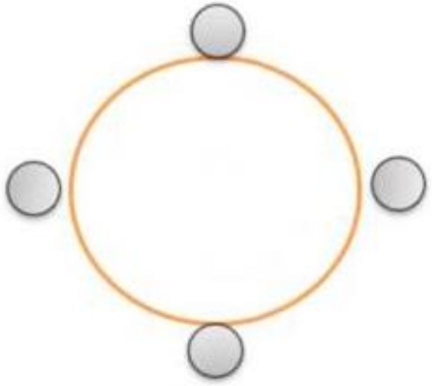
✓ Tanpa beban konsentris

$$l_g = h_{I\ beam} + 2 \times diameter\ baut$$
$$a_g = \frac{1}{2} l_g$$
$$h_g = \frac{5}{3} l_g$$

✓ Dengan beban konsentris

$$l_g = 1\frac{1}{2} b_{I\ beam} + 2 \times diameter\ baut$$
$$a_g = \frac{1}{2} l_g$$
$$h_g = \frac{5}{3} l_g$$

Vertical Plate dengan leg Pipa



Untuk leg tipe pipa

$$l_g = do_{pipa} + 2 \times diameter\ baut$$
$$a_g = \frac{1}{2} l_g$$
$$h_g = \frac{5}{3} l_g$$

Tebal vertical plate

$$t_g = \frac{3}{8} t_{hp}$$

Data Baut

Bolt Size d	Standard Thread: No. of Threads	Standard Thread: Root Area	8-thread Series: No. of Threads	8-thread Series: Root Area	Bolt Spacing*: Minimum B_s	Bolt Spacing*: Preferred	Minimum Radial Distance R	Edge Distance E	Nut Dimension (across flats)	Maximum Fillet Radius r
1/2"	13	0.126	No. 8		1 1/4"	3"	13/16"	5/8"	7/8"	1/4"
5/8"	11	0.202	thread		1 1/2	3	15/16	3/4	1 1/16	5/16
3/4"	10	0.302	series		1 3/4	3	1 1/8	13/16	1 1/4	3/8
7/8"	9	0.419	below 1"		2 1/16	3	1 1/4	15/16	1 7/16	3/8
1"	8	0.551	8	0.551	2 1/4	3	1 3/8	1 1/16	1 5/8	7/16
1 1/8"	7	0.693	8	0.728	2 1/2	3	1 1/2	1 1/8	1 13/16	7/16
1 1/4"	7	0.890	8	0.929	2 13/16	3	1 3/4	1 1/4	2	9/16
1 3/8"	6	1.054	8	1.155	3 1/16		1 7/8	1 3/8	2 3/16	9/16
1 1/2"	6	1.294	8	1.405	3 1/4		2	1 1/2	2 3/8	5/8
1 5/8"	5 1/2	1.515	8	1.680	3 1/2		2 1/8	1 5/8	2 9/16	5/8
1 3/4"	5	1.744	8	1.980	3 3/4		2 1/4	1 3/4	2 3/4	5/8
1 7/8"	5	2.049	8	2.304	4		2 3/8	1 7/8	2 15/16	5/8
2"	4 1/2	2.300	8	2.652	4 1/4		2 1/2	2	3 1/8	11/16
2 1/4"	4 1/2	3.020	8	3.423	4 3/4		2 3/4	2 1/4	3 1/2	11/16
2 1/2"	4	3.715	8	4.292	5 1/4		3 1/16	2 3/8	3 7/8	13/16
2 3/4"	4	4.618	8	5.259	5 3/4		3 3/8	2 5/8	4 1/4	7/8
3"	4	5.621	8	6.324	6 1/4		3 5/8	2 7/8	4 5/8	15/16

* B_s = center-to-center distance between bolts, inches

Diameter baut ditentukan oleh:

$$dbaut = \sqrt{\frac{Abaut^2}{0{,}785}}$$

Dimana :

$$A_{baut} = \frac{P_{baut}}{f_{allowable\ baut}}$$

Dan

$$P_{baut} = \frac{P_{leg}}{n_{baut}}$$

Mendesain Lug

- Mendapatkan informasi tipe leg apakah yang digunakan (Ibeam/pipa)
- Menentukan bhp, lhp, dan thp
- Menentukan lg, ag, hg, dan tg

Desain Lug

Suatu bejana dengan berat total beserta isinya 35000 lb, dan berat tutup atas dan bawah sebesar 1800 lb, akan dipasang penyangga tipe *leg and lug* dengan bentuk *I Beam*. Tinggi total bejana 10 ft dan diameter bejana 5 ft dan tebal silinder 4/16 in sedangkan harga a atau c sebesar 1,5 in. Apabila jumlah penyangga yang digunakan sebanyak 4 buah dengan ukuran 3 in, berat 7,50 lb/ft, dan fondasi dibuat dari beton, desainlah ukuran *lug* pada penyangga tersebut!

Diketahui :
W bejana = 35000 lb
W tutup atas + bawah = 1800 lb
h = 10 ft = 120 in
d = 5 ft = 60 in
ts = 4/16 in
n = 4
a=c= 1.5 in
Ukuran beam = 3 in
Diameter baut = 1 in
f allowable (beton) 12000

Dari table hal. 355
Dept of beam (h) : 3 in
Weight per foot 7.5 lb/ft
Wisth of flane (b) = 2.509 in
Area of section (A) = 2.17 in2
I1-1 = 2.9 in4
I2-2 = 0.59 in4
r1-1 = 1.15 in
r2-2 = 0.52 in

Item 2. Beams, American Standard, Properties of Sections (Continued)

Section Index and Nominal Size	Weight per Foot (lbs)	Area of Section (in.^{2})	Depth of Beam (in.)	Width of Flange (in.) b	Avg Flange Thickness (in.)	Web Thickness (in.)	Axis 1–1 I (in.^{4})	Axis 1–1 S (in.^{3})	Axis 1–1 r (in.)	Axis 2–2 I (in.^{4})	Axis 2–2 S (in.^{3})	Axis 2–2 r (in.)
3″ I												
B 17	7.5	2.17	3	2.509	0.260	0.349	2.9	1.9	1.15	0.59	0.47	0.52
3 x 2⅜	5.7	1.64		2.330	0.260	0.170	2.5	1.7	1.23	0.46	0.40	0.53
R = 0.27												

Tanpa beban konsentris

Mencari lebar, Panjang plate bagian horizontal

Lebar (b_{hp}) = b_{Ibeam} + 2 x d_{baut} = 2,509 + 2 (1) = 4,509 in

Panjang plate (l_{hp}) = h_{Ibeam} + 2 x d_{baut} = 3 + 2 (1) = 5 in

$$\beta = \sqrt{\frac{3(1-\mu^2)}{t_s^2(\frac{1}{2}d)^2}} = \sqrt{\frac{3(1-0{,}33^2)}{,250^2(\frac{1}{2}\,60)^2}} = 0.21$$

$$M = \frac{\beta^3 ts^2 PC\ 1/2d^2}{12(1-\mu^2)b\ h} = \frac{0.21^3(\frac{4}{16})^2\ 9200(1.5)(\frac{1}{2}.60)^2}{12(1-0.33^2)2.509\ (3)} = 20{,}01$$

$$\text{Tebal } thp = \sqrt{\frac{6\,M}{fallowable}} = \sqrt{\frac{6\ (20{,}01)}{12000}} = 0.10 \cong 2/16$$

Standard ukuran plat minimal 3/16 sehinnga thp menjadi 3/16

Mencari lebar dan Panjang plate bagian Vertikal (gusset)

$l_g = h_{lbeam} + 2$ diameter baut $= 3 + 2(1) = 5$ in

$a_g = ½\ l_g = ½ \times 5 = 2{,}5$ in

$h_g = 5/3\ l_g = 5/3 \times 5$ in $= 8{,}33$ in

- thp = 3/16
- tg = 3/8 thp = 3/8 (3/16) = 0.7 ≅ 1/16

tg = 3/16

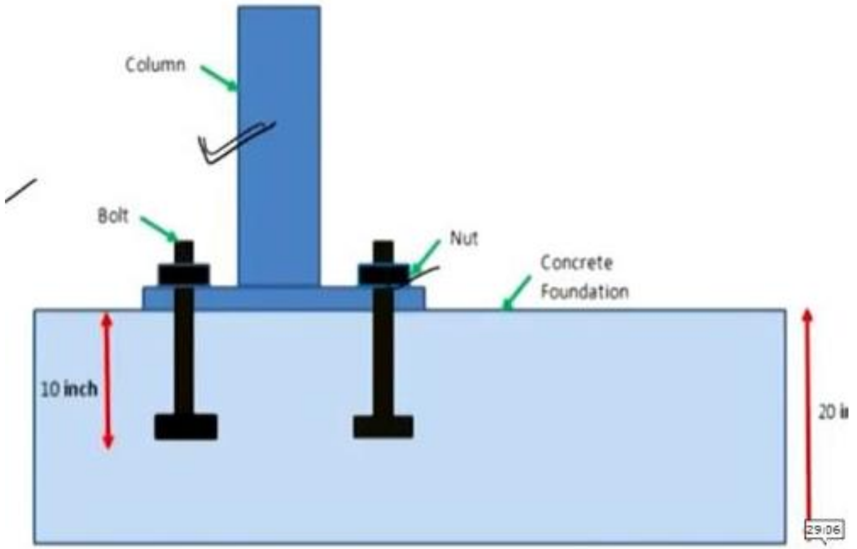
Standard ukuran plat minimal 3/16 sehinnga tg menjadi 3/16

Jadi desain lug tanpa beban konsentris :
Lebar (bhp) = 4.509 in
Panjang plate (lbhp) = 5 in
Tebal horizontal plate (thp) =3/16 in
Tebal vertical plate (tg) = 3/16 in

bearing-plate and anchor-bolt

The bearing plate at the base of support is essential to increase the load-bearing contact area with the foundation.

The bearing-plate, which is welded to the bottom of support of the vessel, must be securely anchored to the concrete foundation by means of anchor bolts embedded in the concrete to prevent overturning from the bending moments induced by the wind loads.



PERANCANGAN ALAT PROSES

"Design of support – Saddle support"

Oleh : Indah Prihatiningtyas D.S

Support to Vessels

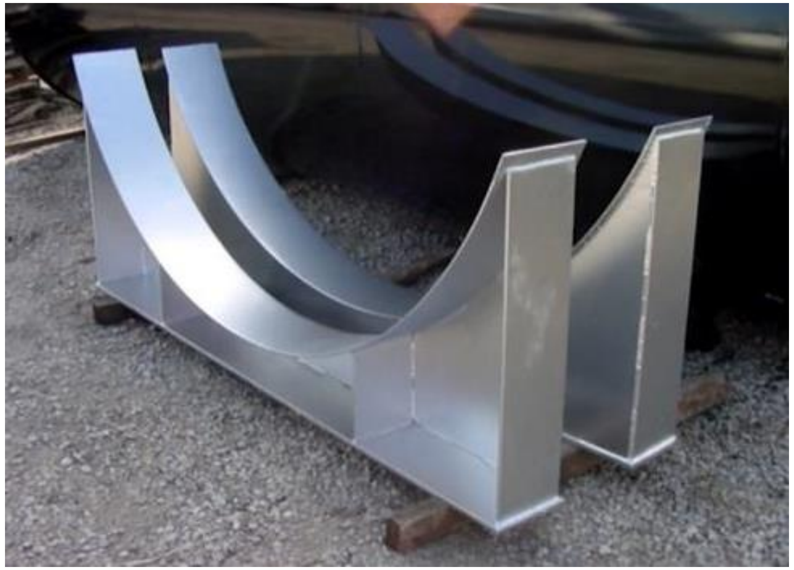
Horizontal vessel

1. Saddle support
2. Leg support ✓

Saddle support

General practice of supporting horizontal cylindrical vessels is by means of saddle support. Number of saddle may be two or more.

Saddle support

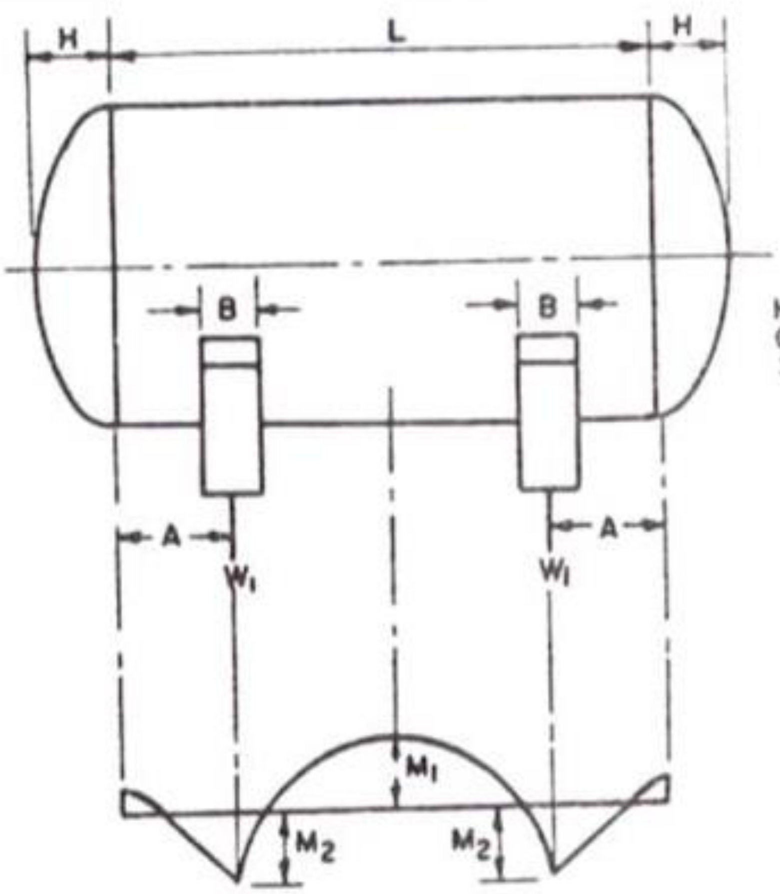


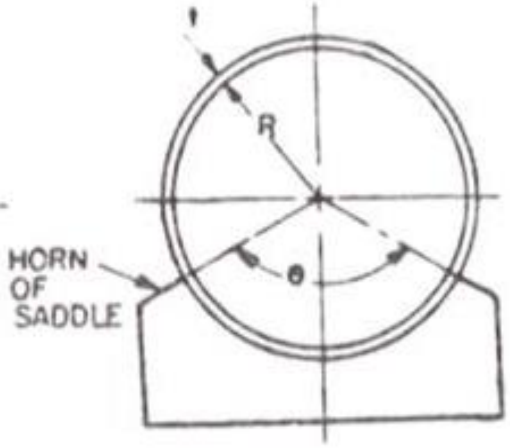
Stress : longitudinal and circumferential

Design saddle dengan menganalisis stress (longitudinal and circumferential) ??????

Saddle Support – Stress analysis

Longitudinal bending moments in shell





At mid-span

$$M_1 = \frac{W_1 L}{4}\left[\frac{1+\frac{2\left(R^2-H^2\right)}{L^2}}{1+\frac{4H}{3L}}-\frac{4A}{L}\right]$$

At supports

$$M_2 = -W_1 A\left[1-\frac{1-\frac{A}{L}+\frac{\left(R^2-H^2\right)}{2AL}}{1+\frac{4H}{3L}}\right]$$

Saddle Support – Stress analysis

Longitudinal bending stress in shell

At the top

$$f_1 = \frac{PR}{2t} - \frac{M_1}{\pi R^2 t}$$

At the bottom

$$f_1' = \frac{PR}{2t} + \frac{M_1}{\pi R^2 t}$$

Longitudinal bending stress at saddle

At the top

$$f_2 = \frac{PR}{2t} - \frac{M_2}{K_1 \pi R^2 t}$$

At the bottom

$$f_2' = \frac{PR}{2t} + \frac{M_2}{K_2 \pi R^2 t}$$

Tensile stresses ≤ f J

Saddle Support – Stress analysis

Tangential shearing stresses

The load is transferred from the unsupported part of the shell to the part over the supports by tangential shearing stresses which vary with the local stiffness of the shell.

Case 1: A > R/2

Maximum tangential shearing stress is given by:

$$q = \frac{K_3 W_1}{R\,t}\left(\frac{L - 2A - H}{L + H}\right)$$

Case 2: A < R/2

In the shell $$q = \frac{K_3 W_1}{R\,t}$$ $$q \leq 0.8 f$$

t = minimum thickness of the shell

In the end $$q_e = \frac{K_4 W_1}{R\,t_e}$$ $$q_e \leq 1.15 f - f_n$$ $$f_n = \frac{P D_o C}{2t}$$

C: Shape factor

te = minimum thickness of the head

Circumferential stresses

At the lowest point of cross-section

$$f_3 = \frac{K_5 W_1}{t(B+10t)}$$

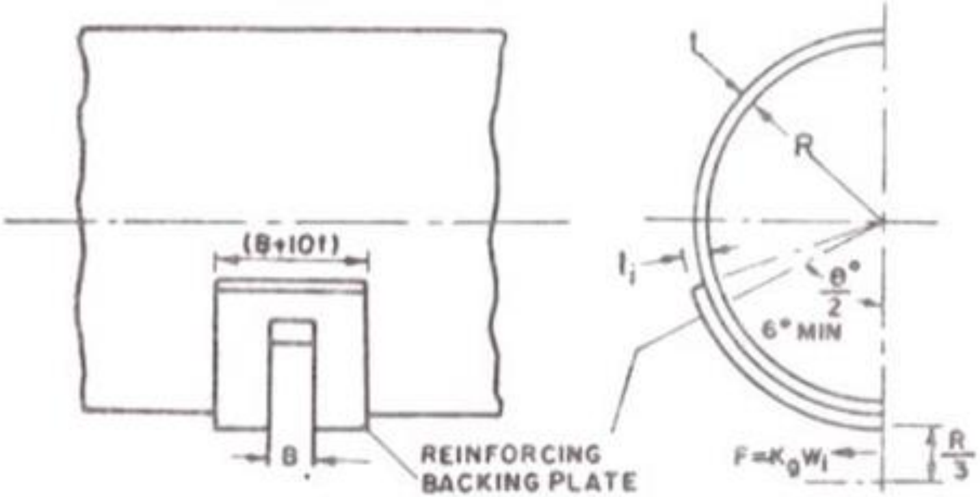
$\leq$ **0.5 Yield pt stress**

At the horn of the saddle

$$f_4 = \frac{-W_1}{4t(B+10t)} - \frac{3\,K_6 W_1}{2t^2}$$ **If L/R > 8**

$$f_4 = \frac{-W_1}{4t(B+10t)} - \frac{12\,K_6 W_1 R}{Lt^2}$$ **If L/R < 8**

Circumferential stress $\leq 1.25\,f$



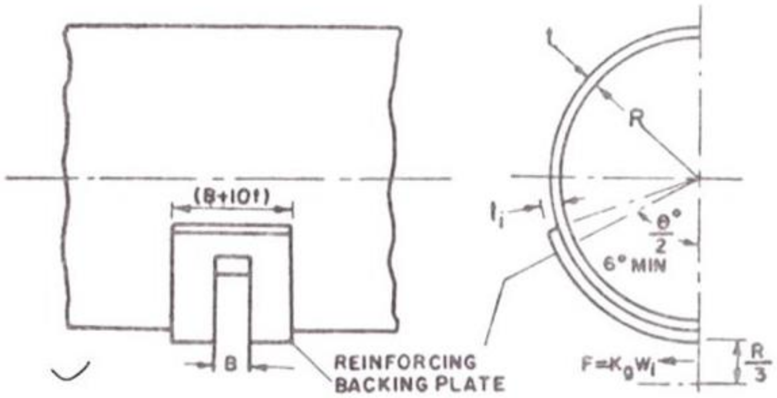
Design of Saddles

Saddle should be strong enough to withstand the forces imposed by the vessel.

Horizontal component of all radial load

$$F = K_9 W_1$$

$$\frac{F}{(R/3)B} \leq 2/3\, f$$



K values — Saddle Support – Stress analysis

VALUES OF CONSTANTS FOR SADDLE SUPPORTS

	K1	K1	K2	K2	K3	K3	K3	K4	K4	K5	K6	K7	K7	K8	K9
Contact **Angle**	A<R/2	A>R/2	A< R/2	A>R/2	Shell stiffened by end of vessel	A>R/2 & (Shell unstiffened by rings OR Shell stiffened by rings adjacent to saddles)	A>R/2 & Shell stiffened by rings in plane of saddles	Shell stiffened by end of vessel & B<A≤ R/2	Shell stiffened by end of vessel & H/2<A <H		See Figure or table 10.5	As per Bhattacharya	As per other books		
120	1	0.107	1	0.192	0.880	1.171	0.319	0.401	0.880	0.760		0.056	0.340	0.0528	0.204
122	1	0.110	1	0.197	0.846	1.139	0.319	0.393	0.846	0.753			0.338	0.051	

K values Saddle Support – Stress analysis

VALUES OF CONSTANTS FOR SADDLE SUPPORTS

	K1	K1	K2	K2	K3	K3	K3	K4	K4	K5	K6	K7	K7	K8	K9
122	1	0.110	1	0.197	0.846	1.139	0.319	0.393	0.846	0.753			0.338	0.051	
124	1	0.113	1	0.202	0.813	1.108	0.319	0.385	0.813	0.746			0.336	0.050	
126	1	0.116	1	0.207	0.781	1.078	0.319	0.377	0.781	0.739			0.334	0.048	
128	1	0.120	1	0.213	0.751	1.050	0.319	0.369	0.751	0.732			0.332	0.047	
130	1	0.123	1	0.219	0.722	1.022	0.319	0.362	0.722	0.726			0.330	0.045	0.222
132	1	0.127	1	0.224	0.694	0.996	0.319	0.355	0.694	0.720			0.328	0.043	
134	1	0.130	1	0.230	0.667	0.971	0.319	0.347	0.667	0.714			0.326	0.042	
136	1	0.134	1	0.235	0.641	0.946	0.319	0.340	0.641	0.708			0.324	0.040	
138	1	0.137	1	0.242	0.616	0.923	0.319	0.334	0.616	0.702			0.322	0.039	
140	1	0.141	1	0.248	0.592	0.900	0.319	0.327	0.592	0.697			0.320	0.037	0.245
142	1	0.145	1	0.253	0.569	0.879	0.319	0.320	0.569	0.692			0.316	0.036	
144	1	0.149	1	0.259	0.547	0.858	0.319	0.314	0.547	0.687			0.312	0.035	
146	1	0.153	1	0.264	0.526	0.837	0.319	0.308	0.526	0.682			0.308	0.034	
148	1	0.157	1	0.271	0.505	0.818	0.319	0.301	0.505	0.678			0.304	0.033	
150	1	0.161	1	0.279	0.485	0.799	0.319	0.295	0.485	0.673		0.021	0.300	0.0316	0.259
152	1	0.165	1	0.284	0.466	0.781	0.319	0.289	0.466	0.669			0.298	0.031	
154	1	0.169	1	0.291	0.448	0.763	0.319	0.283	0.448	0.665			0.296	0.030	
156	1	0.173	1	0.297	0.430	0.746	0.319	0.278	0.430	0.661			0.294	0.028	
158	1	0.177	1	0.304	0.413	0.729	0.319	0.272	0.413	0.657			0.292	0.027	

K values Saddle Support – Stress analysis

VALUES OF CONSTANTS FOR SADDLE SUPPORTS

	K1	K1	K2	K2	K3	K3	K3	K4	K4	K5	K6	K7	K7	K8	K9
160	1	0.182	1	0.311	0.396	0.713	0.319	0.266	0.396	0.654			0.290	0.026	0.279
162	1	0.186	1	0.316	0.380	0.698	0.319	0.261	0.380	0.650			0.286	0.025	
164	1	0.191	1	0.322	0.365	0.683	0.319	0.256	0.365	0.647			0.282	0.024	
166	1	0.195	1	0.329	0.350	0.668	0.319	0.250	0.350	0.643			0.278	0.024	
168	1	0.200	1	0.335	0.336	0.654	0.319	0.245	0.336	0.640			0.274	0.023	
170	1	0.204	1	0.343	0.322	0.640	0.319	0.240	0.322	0.637			0.270	0.022	0.298
172	1	0.209	1	0.349	0.309	0.627	0.319	0.235	0.309	0.635			0.266	0.021	
174	1	0.214	1	0.355	0.296	0.614	0.319	0.230	0.296	0.632			0.262	0.020	
176	1	0.022	1	0.362	0.283	0.601	0.319	0.225	0.283	0.629			0.258	0.019	
178	1	0.223	1	0.368	0.271	0.589	0.319	0.220	0.271	0.627			0.254	0.018	
180	1	0.228	1	0.376	0.260	0.577	0.319	0.216	0.260	0.624			0.250	0.017	0.318

Table 10.3 Values of Factors K_1 and K_2

Condition	Saddle Angle (θ)	K_1	K_2
Shell stiffened by end or rings (i.e. $A < R/2$ or rings provided)	120	1	1
	150	1	1
Shell unstiffened by end or rings (i.e. $A > R/2$ and no rings provided)	120	0.107	0.192
	150	0.161	0.279

Table 10.4 Values of Factors[5] K_3 and K_4

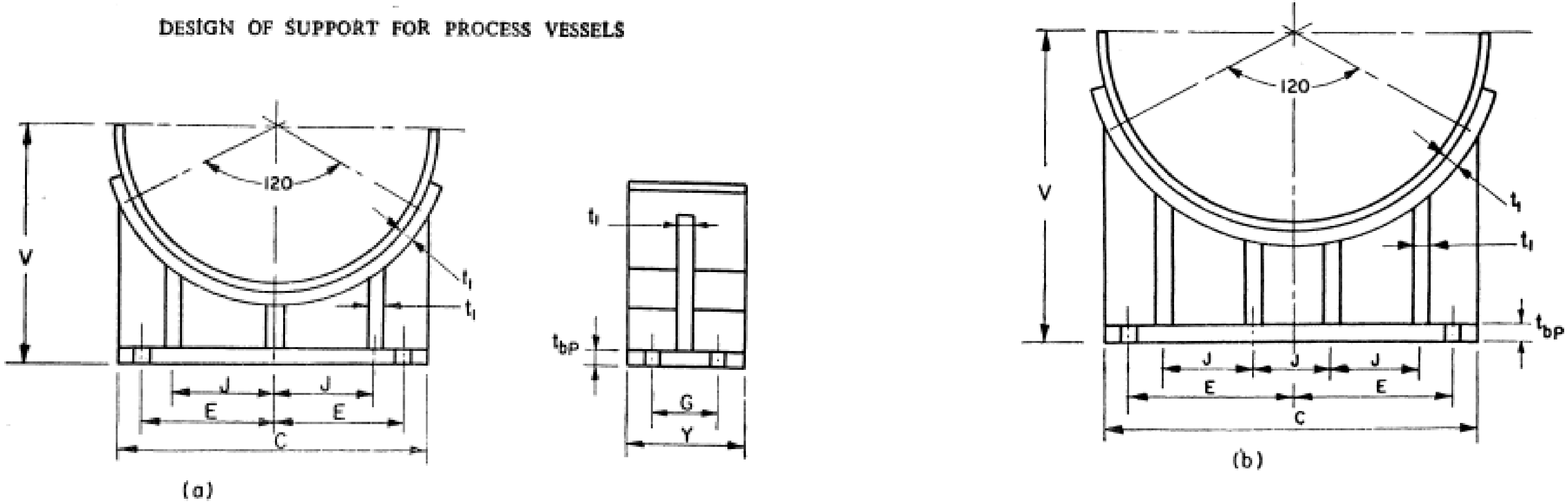
Condition		Saddle Angle (θ)	K_3	K_4
$A > R/2$ and shell unstiffened by rings		120	1.171	...
		150	0.799	...
$A > R/2$ and shell stiffened by rings in plane of saddles		120	0.319	...
		150	0.319	...
$A > R/2$ and shell stiffened by rings adjacent to saddles		120	1.171	...
		150	0.799	...
Shell stiffened by end of vessel	$B < A \leqslant R/2$	120	0.880	0.401
		150	0.485	0.297
	$\frac{H}{2} < A < H$	120	0.880	0.880
		150	0.485	0.485

Table 10.5 Values of K_6

A/R	$\theta = 120°$	$\theta = 150°$
0 — 0.5	0.013	0.007
0.6	0.018	0.010
0.7	0.030	0.017
0.8	0.034	0.021
0.9	0.047	0.028
1.0	0.052	0.031
1.1 – 3.0	0.055	0.033

General practice of saddle location suggests $A = 0.2\ L$.

Table 10.7, with reference to Fig. 10.6, gives the standard dimensions for saddles used in practice.



(a) FOR VESSEL DIA. 1.2 m AND UNDER

(b) FOR VESSEL DIA. OVER 1.2 m

Fig. 10.6 Standard construction of steel saddles (Table 10.7)

Table 10.7 Standard Dimensions for Saddles (Fig. 10.6)

Vessel Diam. (m)	*Maximum operating weight (kN)*	*All dimensions in* (m)						*All dimensions in* (mm)					
		V	Y	C	E	J	G	t_{bp}	t_1	*Bolt Diam.*	*Bolt Holes*	*Slotted Holes*	*Fillet Welds*
0.6	35	0.48	0.15	0.55	0.24	0.190	0.095	6	5	20	25	25 × 37	5
0.8	50	0.58	0.15	0.70	0.29	0.225	0.095	8	5	20	25	25 × 37	5
0.9	65	0.63	0.15	0.81	0.34	0.275	0.095	10	6	20	25	25 × 37	5
1.0	90	0.68	0.15	0.91	0.39	0.310	0.095	11	8	20	25	25 × 37	5
1.2	180	0.78	0.20	1.09	0.45	0.360	0.140	12	10	24	30	30 × 45	6
1.4	230	0.88	0.20	1.24	0.53	0.305	0.140	12	10	24	30	30 × 45	6
1.6	330	0.98	0.20	1.41	0.62	0.350	0.140	12	10	24	30	30 × 45	6
1.8	380	1.08	0.20	1.59	0.71	0.405	0.140	12	10	24	30	30 × 45	6
2.0	460	1.18	0.20	1.77	0.80	0.450	0.140	12	10	24	30	30 × 45	6
2.2	750	1.28	0.225	1.95	0.89	0.520	0.150	16	12	24	30	30 × 45	10
2.4	900	1.38	0.225	2.13	0.98	0.565	0.150	16	12	27	33	33 × 52	10
2.6	1 000	1.48	0.225	2.30	1.03	0.590	0.150	16	12	27	33	33 × 52	10
2.8	1 350	1.58	0.25	2.50	1.10	0.625	0.150	16	12	27	33	33 × 52	10
3.0	1 750	1.68	0.25	2.64	1.18	0.665	0.150	16	12	27	33	33 × 52	10
3.2	2 000	1.78	0.25	2.82	1.26	0.730	0.150	16	12	27	33	33 × 52	10
3.6	2 500	1.98	0.25	3.20	1.40	0.815	0.150	16	12	27	33	33 × 52	10

Note : Continuous fillet welds all round. Maximum allowable working stress 95 MN/m^2.

Design of Saddle Support

Design a saddle support for a horizontal drum (designed for internal pressure of 2.1 MN/m^2) having inside radius = 1.2m. tangent to tangent length = 15 m, depth of dish of head = 0.4m. The allowable stress and yield point of material is 150 MN/m^2 and 240 MN/m^2, corrosion allowance = 0, weld joint efficiency factor = 1, Modulus of elasticity = 2×10^5 MN/m^2, load on each saddle = 1.4×10^6 N, contact angle = 120°.

Check if the following assumed saddle design data [A/R=0.6 and B=0.5m] satisfy all design stress conditions. If not, find the new values of A/R and B, which satisfy all design stress conditions.

Diketahui :

P = 2.1 MN/m2

Ri = 1.2 m , Di= 2.4 m

L = 15 m

H = 0.4 m

S = 150 MN/m2

f / fj = 150 MN/m2

yield point of material 240 MN/m2

C = 0

E = 1

Modulus elasticity = 2 x 10^5 MN/m2

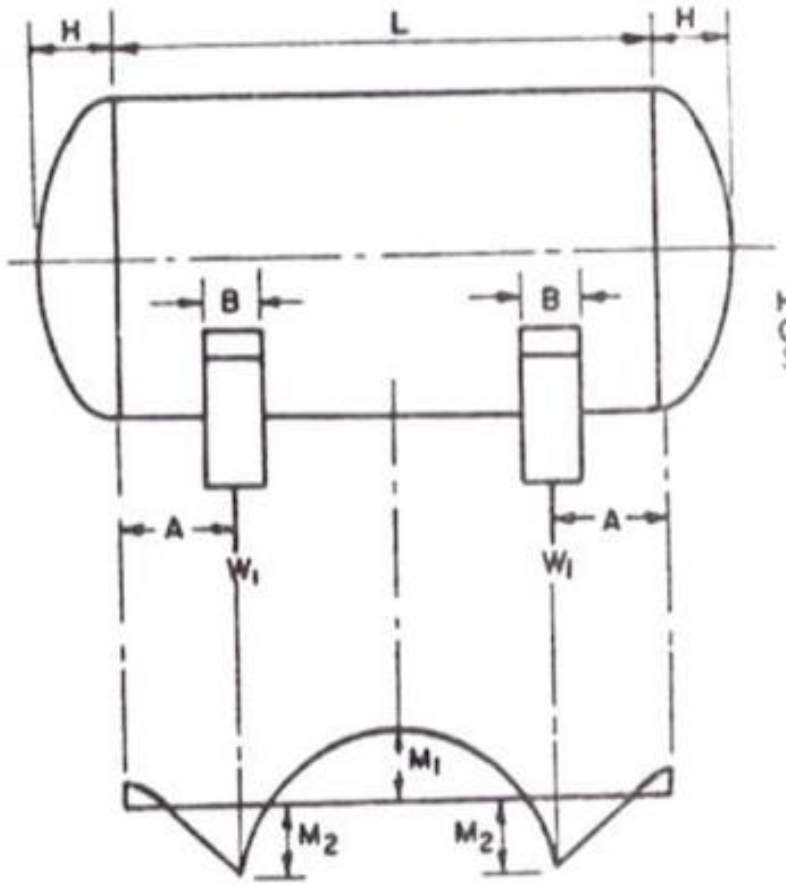
W1 = 1.4 x 10^6 N = 1.4 MN

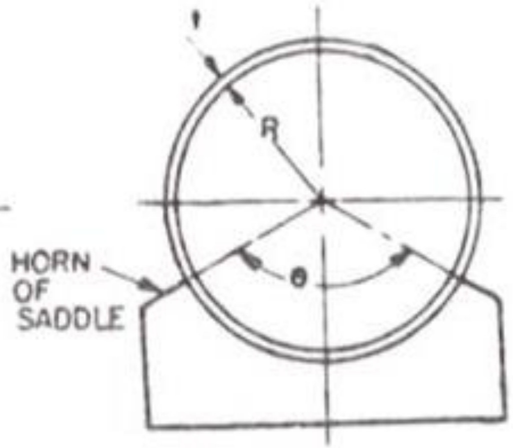
contact angle : 120

A/R = 0.6 , sehingga A = 0.72 m

B = 0.5 m

Longitudinal bending moments in shell





$$M_1 = \left(\frac{W_1 L}{4}\right)\left[\left(\frac{1+2\left(\frac{R^2-H^2}{L^2}\right)}{1+\left(\frac{4H}{3L}\right)}\right) - \left(\frac{4A}{L}\right)\right] = 4.119 \text{ MNm}$$

$$M_2 = -(W_1 A)\left[1 - \left(\frac{1-\left(\frac{A}{L}\right)+\left(\frac{R^2-H^2}{2AL}\right)}{1+\left(\frac{4H}{3L}\right)}\right)\right]$$

$$= -1.4 * 10^6 * 0.72\left[1 - \left(\frac{1-\left(\frac{0.72}{15}\right)+\left(\frac{1.2^2-0.4^2}{2*0.72*15}\right)}{1+\left(\frac{4*0.4}{3*15}\right)}\right)\right]$$

$$= -0.0236 \text{ MNm}$$

PERANCANGAN ALAT PROSES

Heat Exchanger

Oleh : Indah Prihatiningtyas D.S

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact.

In heat exchangers, there are usually no external heat and work interactions. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner.

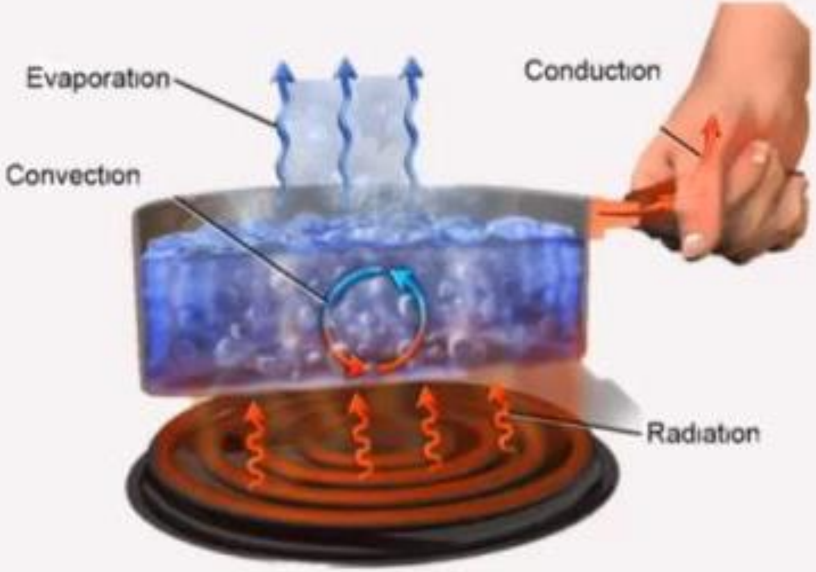
BASIC OF HEAT TRANSFER

The form of energy that can be transferred form one system to another as a result of temperature difference

A temperature difference is the driving force by which heat is transferred form a source to a receiver

Thermal Convection

Perpindahan panas melalui aliran yang zat perantaranya ikut berpindah. Jika partikel berpindah dan mengakibatkan kalor merambat, terjadilah konveksi. Konveksi terjadi pada zat cair dan gas (udara/angin).



Thermal Conduction

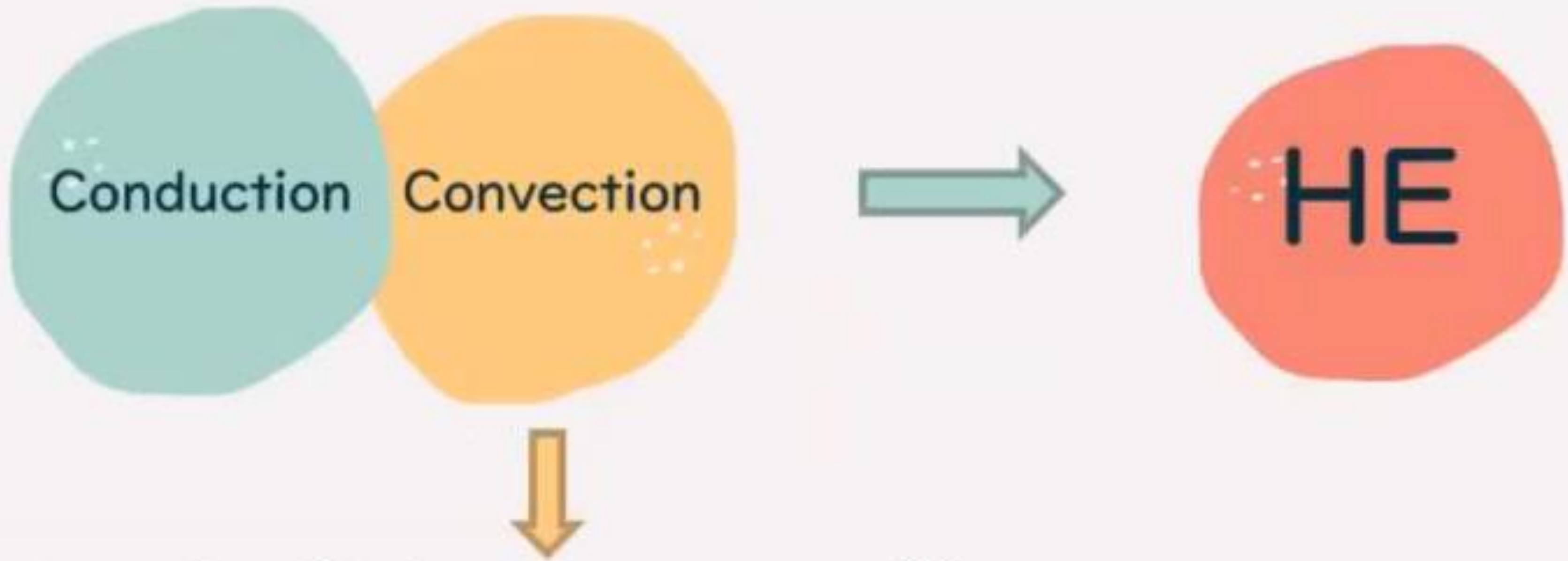
Perpindahan panas melalui zat padat yang tidak ikut mengalami perpindahan. Artinya, perpindahan kalor pada suatu zat tersebut tidak disertai dengan perpindahan partikel-partikelnya.

Thermal Radiation

Perpindahan kalor tanpa zat perantara merupakan radiasi. Radiasi adalah perpindahan panas tanpa zat perantara

HEAT EXCHANGER

The equipment used to implement heat exchange between two flowing fluids that are at different temperatures and separated by a solid wall.



LMTD = *logarithmic mean temperature difference*

F = correction factor

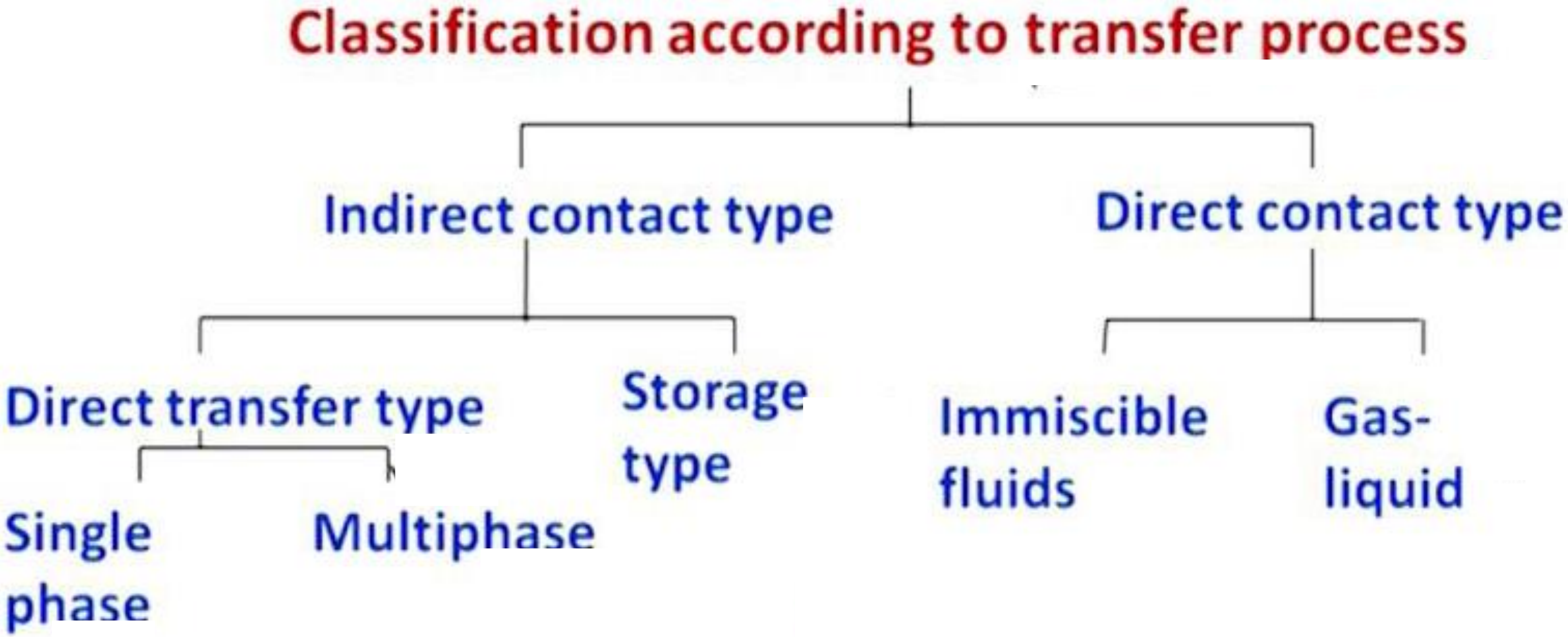
Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger.

There could be internal thermal energy sources in the exchangers, such as in electric heaters and nuclear fuel elements.

Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers.

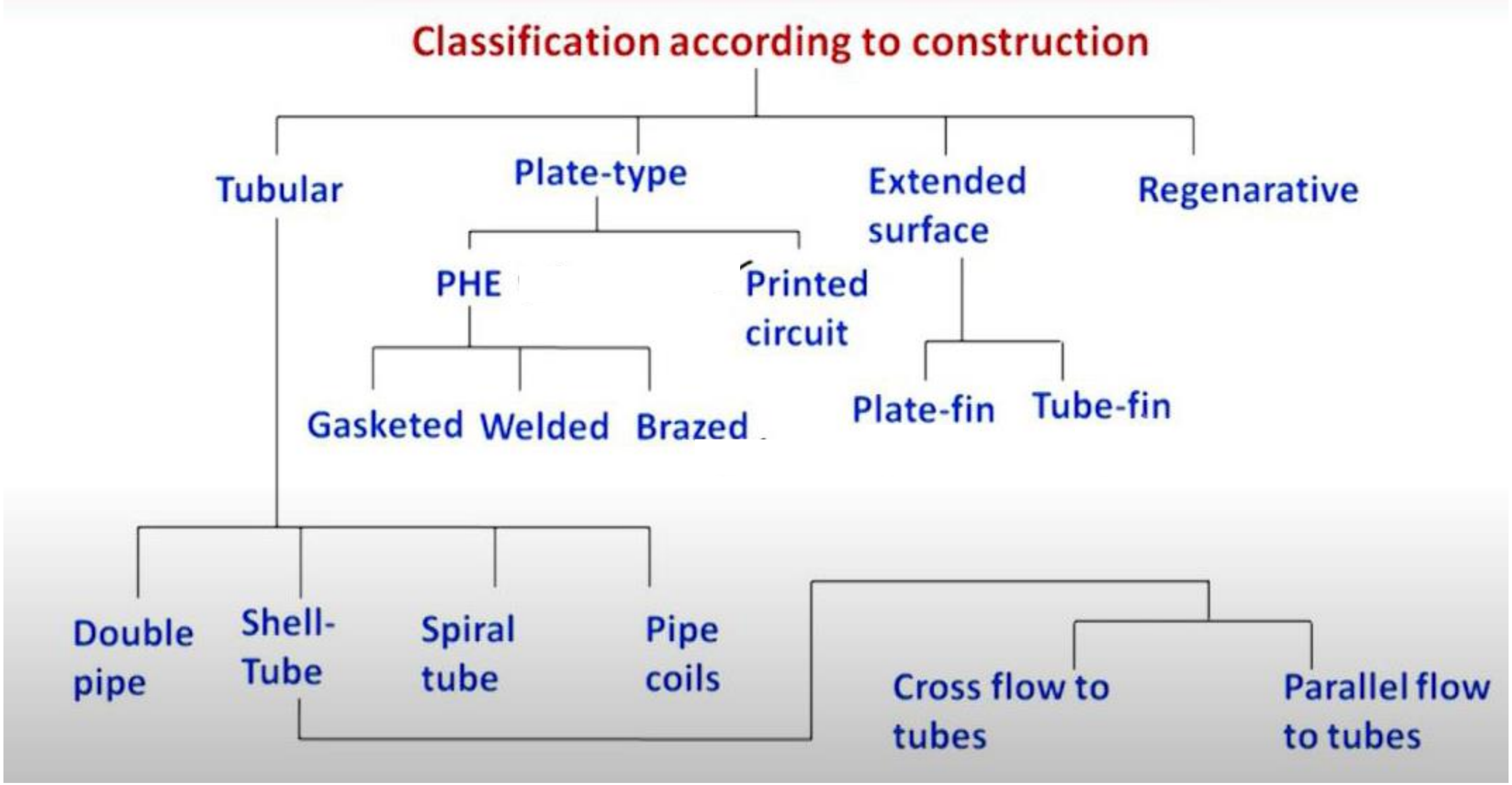
Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors.

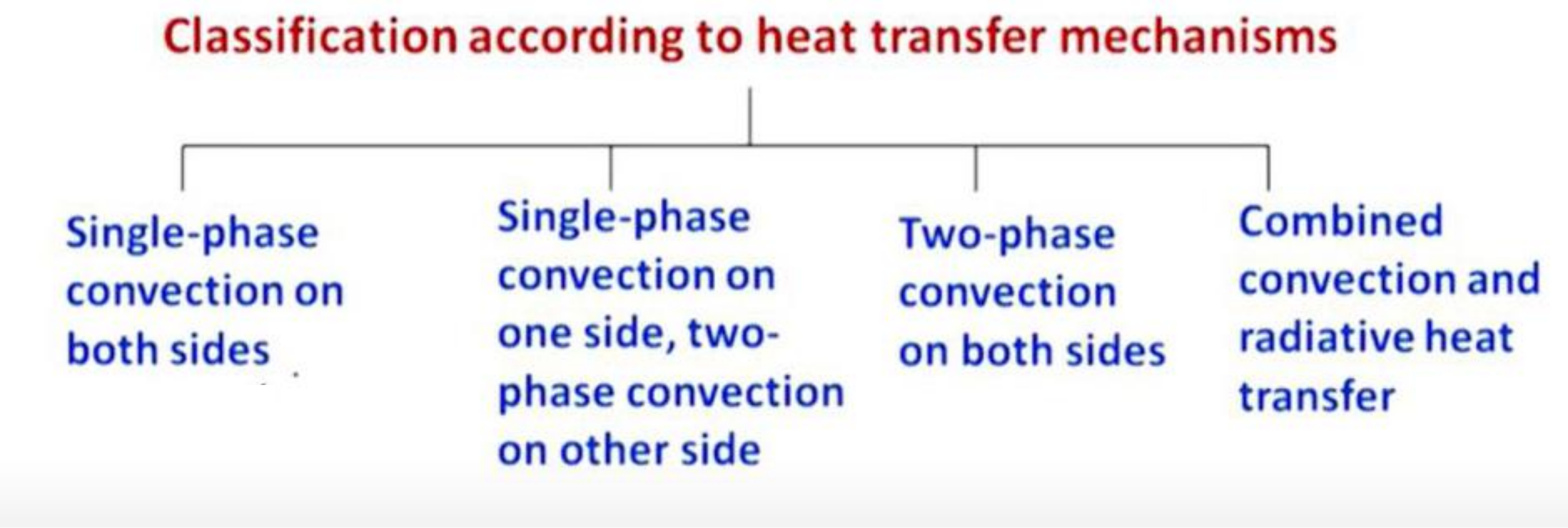
- ✓ Heat exchangers are classified according to transfer processes, degree of surface compactness, construction features and heat transfer mechanisms.



Classification according to surface compactness

- **Gas- to- fluid**
  - Compact ($\beta \geq 700\ m^2/m^3$)
  - Noncompact ($\beta < 700\ m^2/m^3$)
- **Liquid-to-liquid**
  - Compact ($\beta \geq 400\ m^2/m^3$)
  - Noncompact ($\beta < 400\ m^2/m^3$)


Classification according to construction
Tubular
Plate-type
Extended surface
Regenarative
PHE
Printed circuit
Gasketed
Welded
Brazed
Plate-fin
Tube-fin
Double pipe
Shell-Tube
Spiral tube
Pipe coils
Cross flow to tubes
Parallel flow to tubes



Shel and tube HE | kondenser | Reboiler | Boiler

TYPES OF HEAT EXCHANGER

According to the flow arrangements

Single past:
fluids flow by each other only once in the system

Multi past:
fluids are looped back to flow each other multiple times

Counter flow:
fluids flow opposite directions toward each other

Cross flow:
fluids flow perpendicular to each other

Co-current flow:
fluids flow parallel to each other

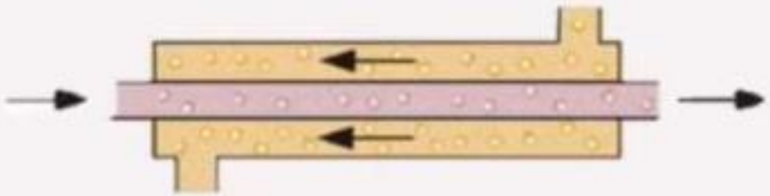


Figure 1. Countercurrent flow

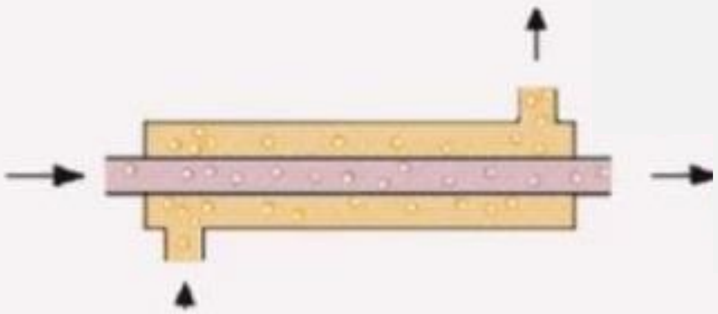


Figure 2. Cocurrent flow

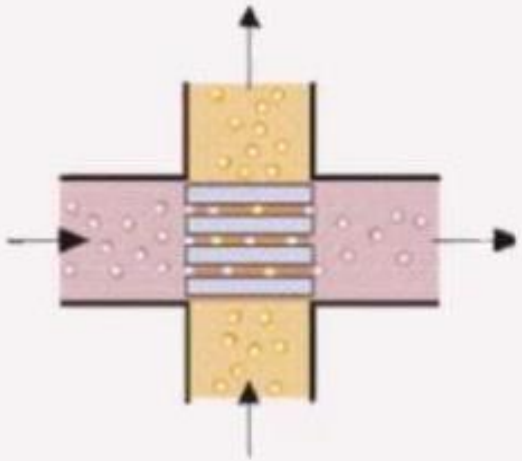


Figure 3. Crossflow.

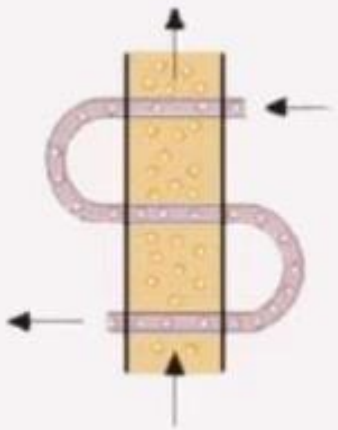


Figure 4. Cross/counter flow

According to construction

Cleanability – how easy the equipment is to clean

Compactness – how small or large the equipment's footprint is

Ease of repair – how easy the equipment is to maintain and repair

Extension – how easily the equipment can be modified or extended

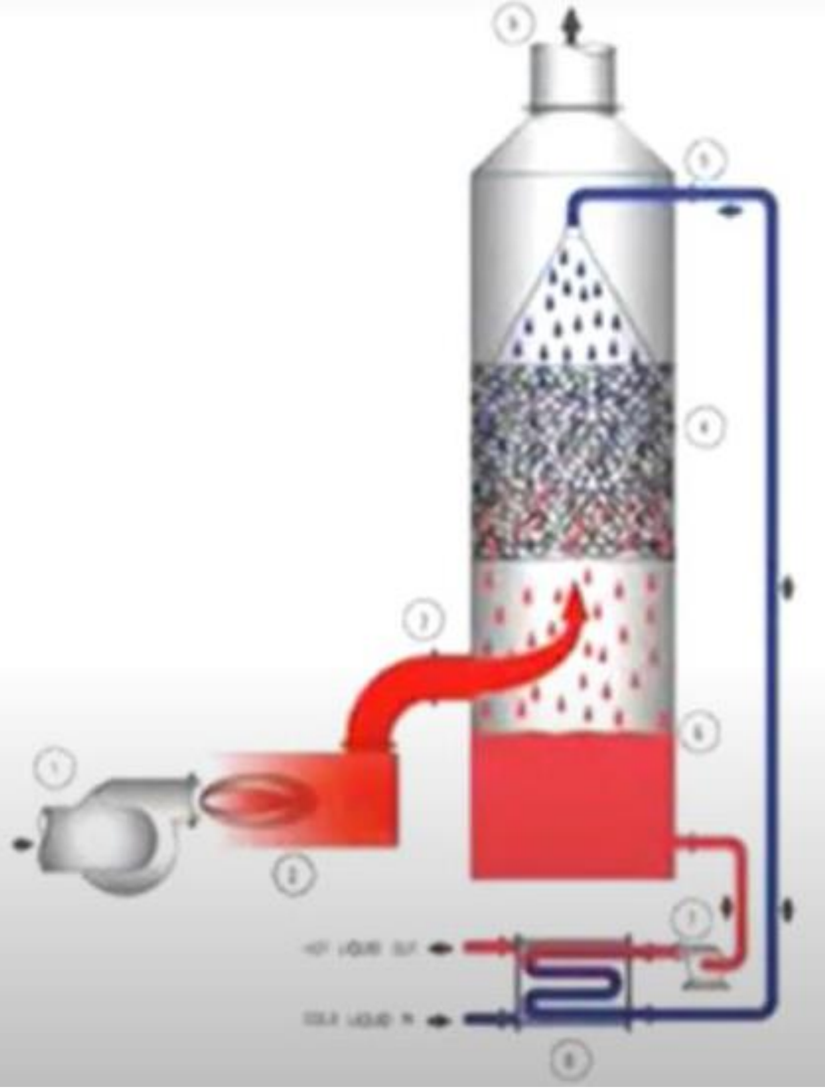
Plugging risk – how susceptible the equipment is to fouling or clogging.

Direct-contact heat exchanger

- In direct-contact heat exchanger the hot and cold streams are brought into contact without any separating wall, and high rates of heat transfer are achieved.

- The equipment used is basically simple and cheap, and is suitable for use with heavily fouling fluids and with liquids containing solids.

- Water-cooling towers are a particular example of direct-contact heat exchanger.

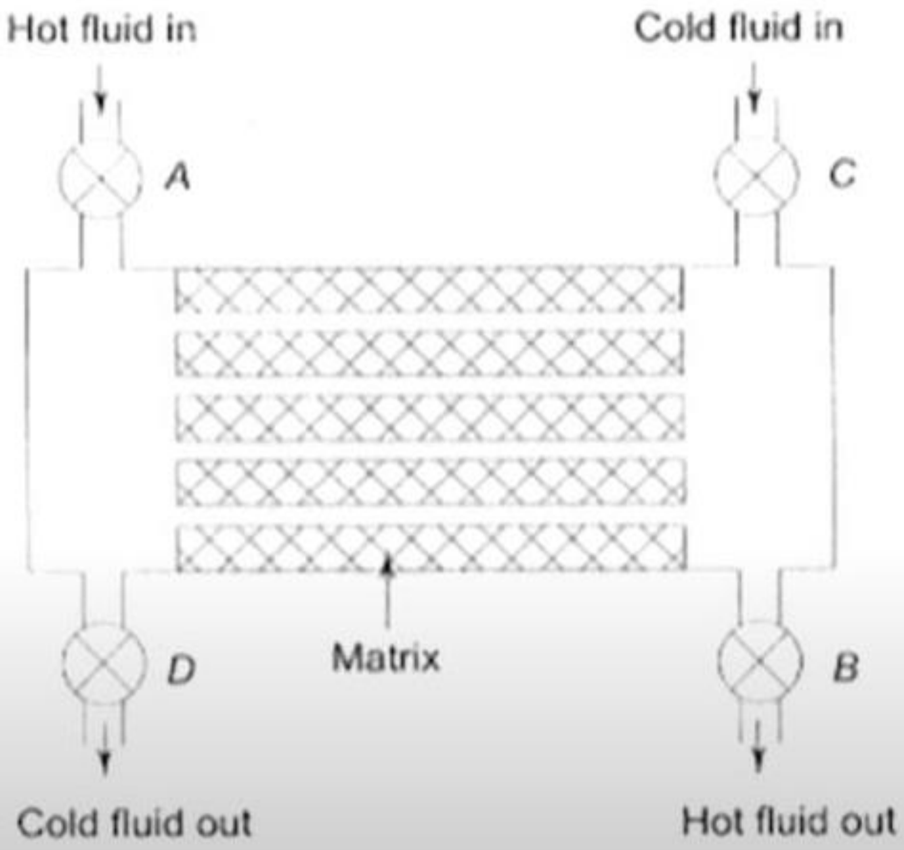


Storage type heat exchanger

In the regenerators, the hot and cold fluids flow alternatively through a solid matrix of high heat capacity. When the hot fluid flows through the matrix in an interval of time, heat is transferred from the fluid to the matrix, which stores it in the form of an increase in its internal energy. This stored energy is then transferred to the cold fluid as it flows through the matrix in the next interval of time. The matrix is then subjected to periodic heating and cooling.

Storage type heat exchanger

During the heating period of the cycle when the hot fluid flows through the matrix, valves A and B are kept open and C and D are kept close. During the cooling period, valves A and B are kept close and C and D are kept open. A regenerator with a stationary matrix is used in a Stirling refrigerator, such as Philips refrigerating machine for liquefaction of air, and in a gas turbine power plant.



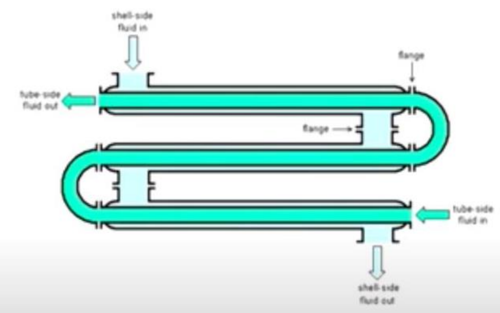
Double – pipe Heat Exchanger

- It is a simplest heat-exchange device
- It is easy to fabricate.
- Its name is derived from the fact that it is fabricated using two concentric pipes.
- One fluid flows inside the inner pipe while the second fluid flows in the annular space between the two pipes.
- Other advantages include low installation cost, ease of maintenance and flexibility.

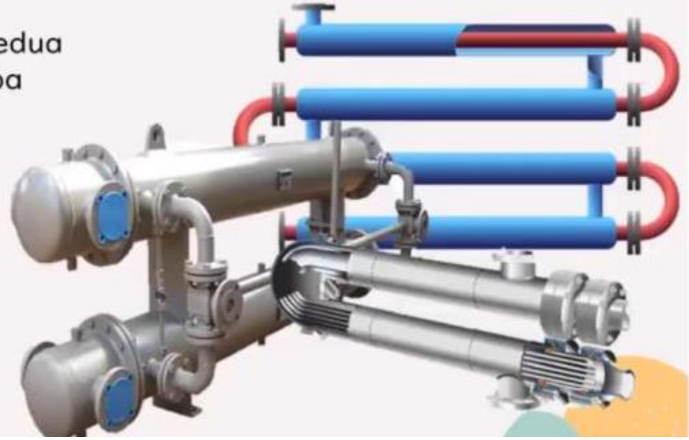
Double-pipe exchangers are generally used for small-capacity applications where the total heat transfer surface area required is $50 m^2$ ($500 ft^2$) or less because it is expensive on a cost per unit surface area basis.

This configuration is also suitable where one or both of the fluids is at very high pressure, because containment in the small-diameter pipe or tubing is less costly than containment in a large-diameter shell.

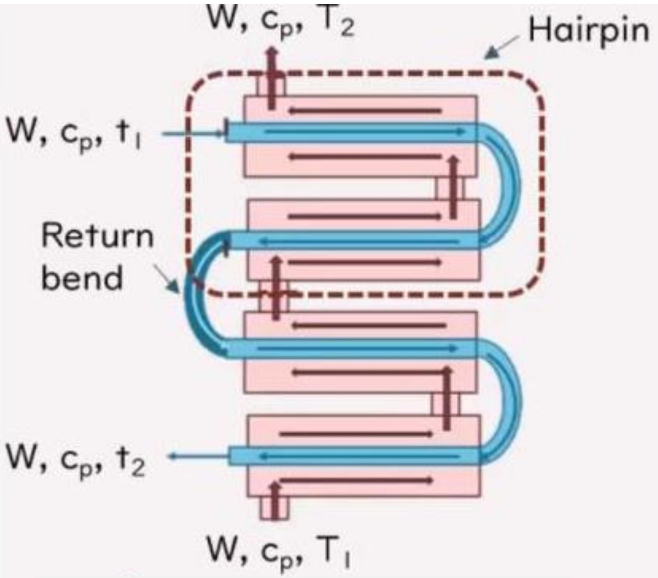
Double – pipe Heat Exchanger



- Alat penukar panas pipa rangkap (terdiri dari 2 pipa)
- Fluida 1 mengalir di dalam pipa, fluida kedua mengalir di dalam ruang anulus antar pipa lur dengan pipa dalam
- L = 12, 15, 20 ft
- Luas perpindahan panas = <120 ft^2



Double – pipe Heat Exchanger

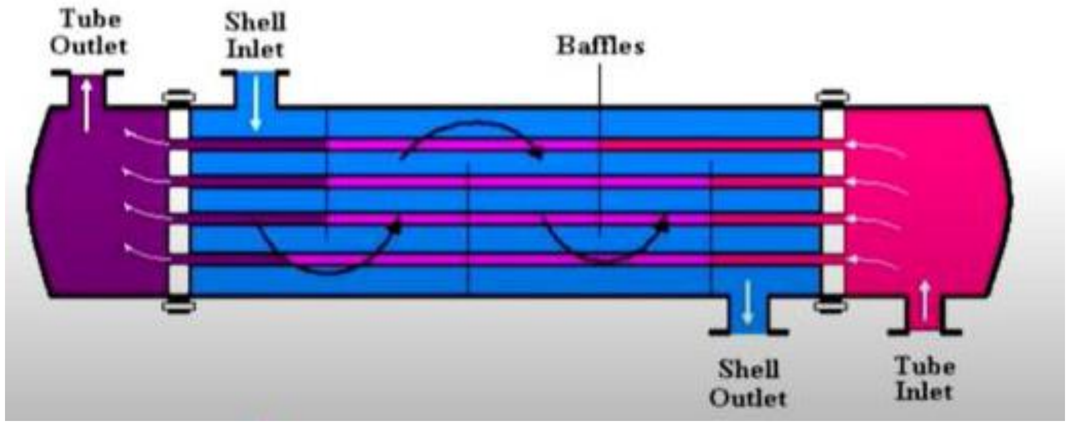


- Advantages of Double Pipe Heat Exchangers:
  1. Simplest type of heat exchangers
  2. Can be easily assembled
  3. Relatively low cost/ft^2
  4. Small sizes results in high Re

- Disadvantages of Double Pipe Heat Exchangers:
  1. Leakages are very common
  2. Requires a lot of time in dismantling and cleaning
  3. Small surface area of heat transfer/pipe
  4. Space requirements are large

Shell and tube Heat Exchanger

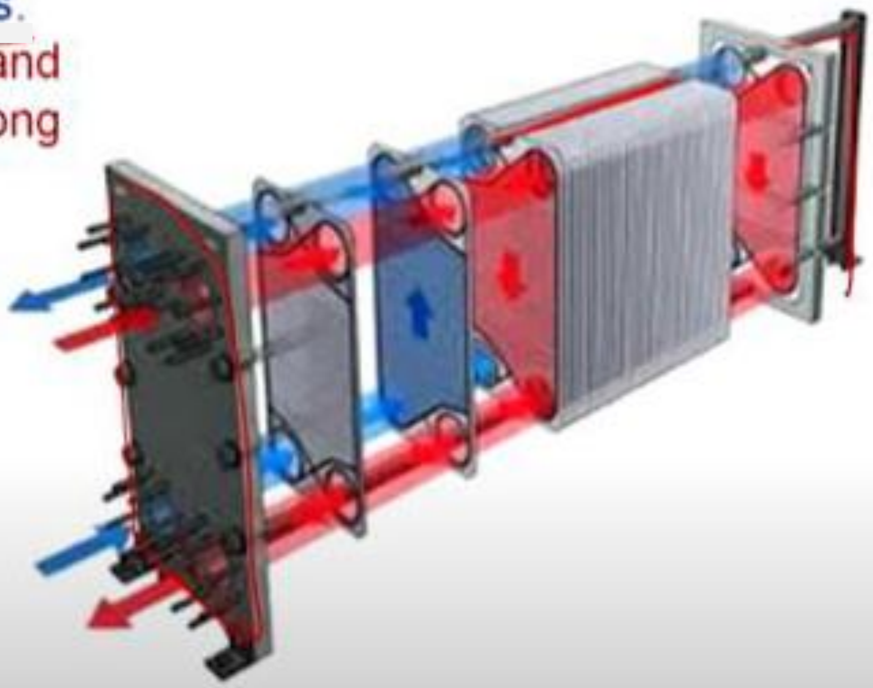
- The shell and tube exchanger is most commonly used type of heat-transfer equipment used in the chemical industries.
- It consists of a bundle of tubes enclosed in a cylindrical shell.
- The ends of the tubes are fitted into tube sheets, which separate the shell-side and tube-side fluids.
- Baffles are provided in the shell to direct the fluid flow and support the tubes.



The tubes in form of a bundle may be permanently positioned inside the shell (fixed tube-sheet exchanger) or may be removable for ease of cleaning and replacement (floating-head or U-tube exchanger). Shell and tube exchangers are also used as condensers, reboiler and vaporisers.

Plate Type Heat Exchanger

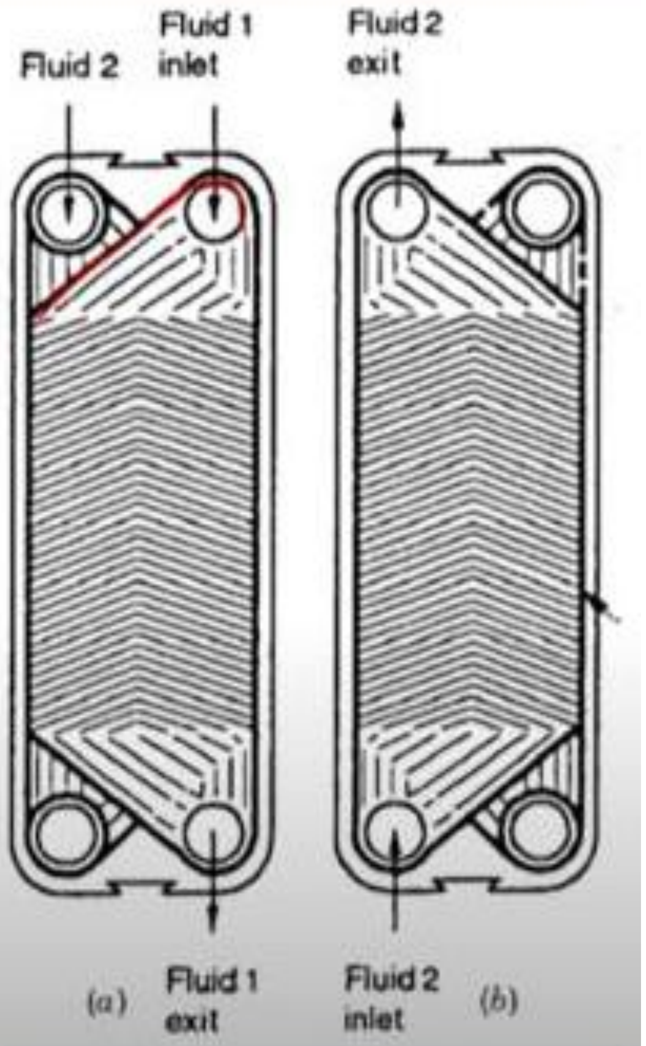
- It consists of a series of rectangular, parallel plates held firmly together between substantial head frames.
- The plates have corner ports and are sealed and spaced by rubber gaskets around the ports and along the plate edges.
- The plates can have flat or corrugated faces.
- These plates serve as heat transfer surfaces.



Gasketed Plate Heat Exchangers

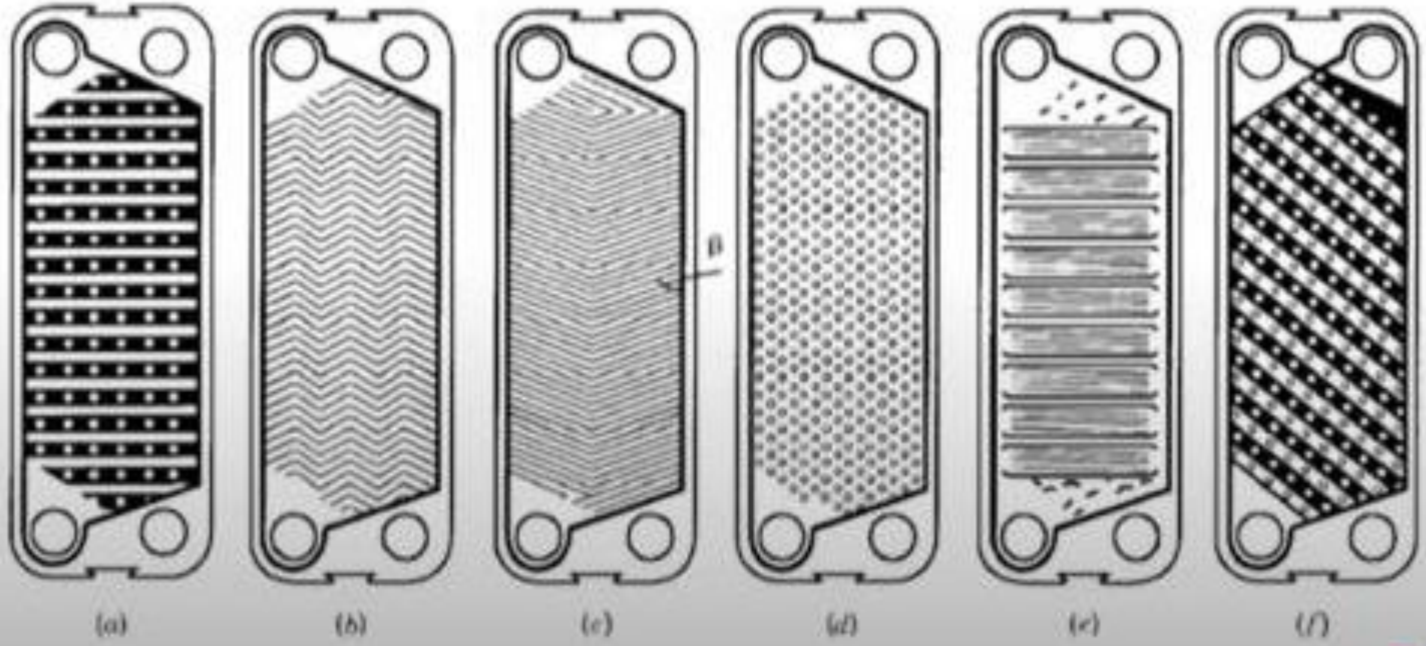
The plate-and-frame or gasketed plate heat exchanger (PHE) consists of a number of thin rectangular metal plates sealed around the edges by gaskets and held together in a frame.

In the frame, the plates are suspended from an upper carrying bar and guided by a bottom carrying bar to ensure proper alignment. For this purpose, each plate is notched at the center of its top and bottom edges.



Gasketed Plate Heat Exchangers

Typical plate geometries (corrugated patterns) are shown in the figure and over 60 different patterns have been developed worldwide.



(a) Washboard
(b) Zigzag
(c) Chevron or herringbone
(d) Protrusions and depressions
(e) Washboard with secondary corrugations
(f) Oblique washboard

Extended Surface Heat Exchangers

Tube-Fin Heat Exchangers

In a tube-fin exchanger, round and rectangular tubes are most common, although elliptical tubes are also used. Fins are generally used on the outside, but they may be used on the inside of the tubes in some applications. They are attached to the tubes by a tight mechanical fit, adhesive bonding, soldering, brazing, welding, etc.

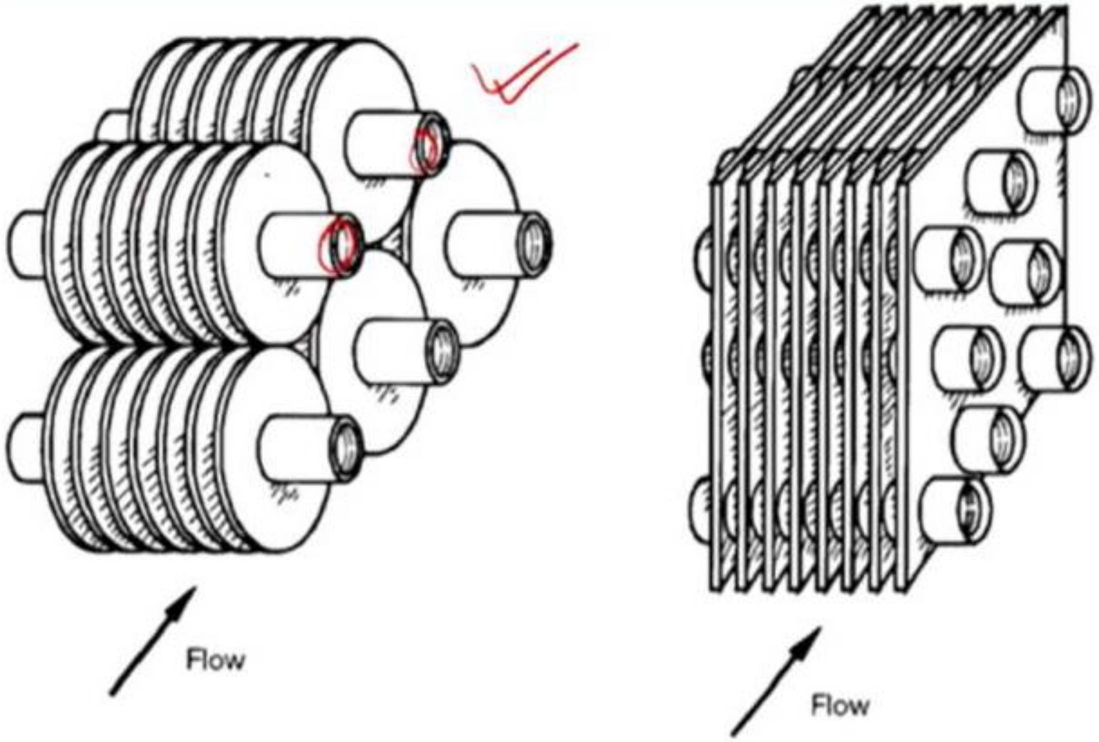
Extended Surface Heat Exchangers

Tube-Fin Heat Exchangers

Depending on the fin type, tube-fin exchangers are categorized as follows:

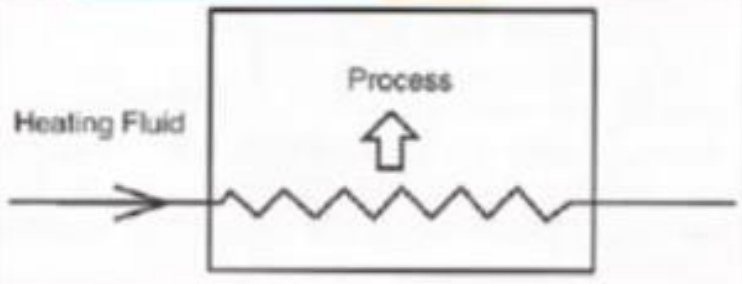
(1) an individually finned tube exchanger or simply a finned tube exchanger having normal fins on individual tubes; and

(2) a tube-fin exchanger having flat (continuous) fins.

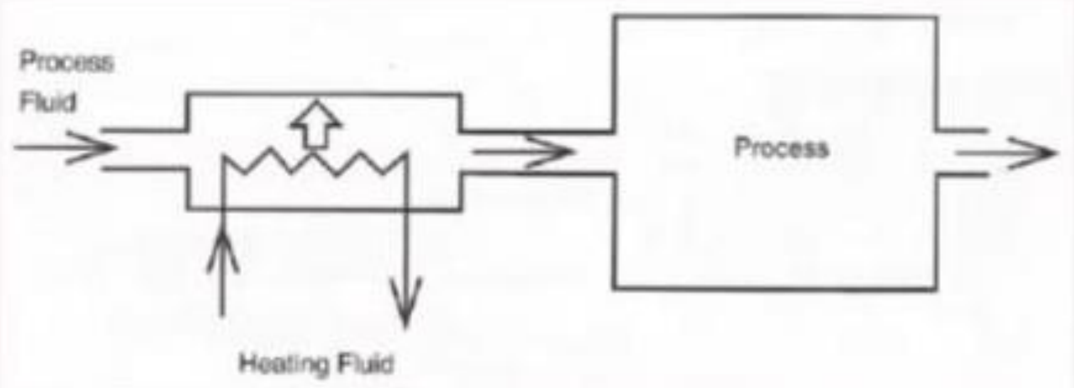


(a) Individually finned tubes; (b) flat (continuous) fins on an array of tubes

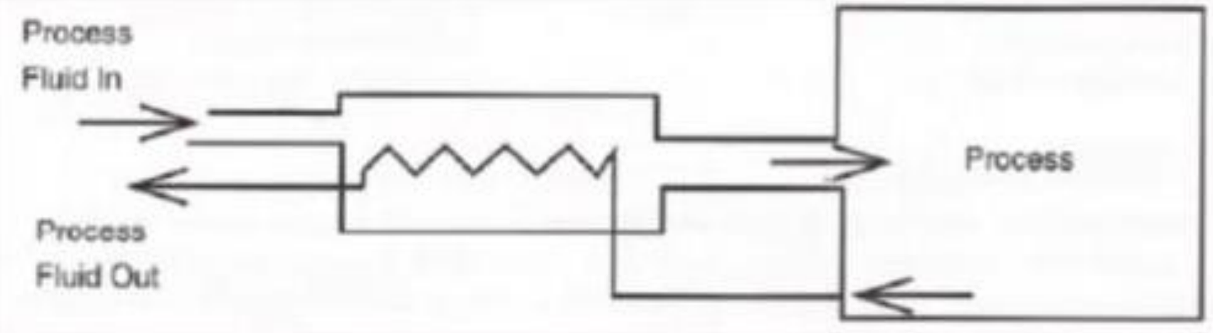
PROCESS CONFIGURATIONS



integral with process



separate with process



recovery of waste heat

DPHE vs STHE

Double Pipe Heat Exchanger

- These exchangers have a 'tube in tube heat exchanger' structure which gives them this name. Often the double pipes in these exchangers have a **'U-tube or Hairpin structure'**.
- These exchangers can be used for high pressure, high temperature and highly viscous service
- Luas Perpindahan Panas < 120 ft^2
- Panjang pipe = 12, 15, 20 ft

Shell and Tube Heat Exchanger

- Consists of a number of tubes mounted inside a cylindrical shell
- Provide relatively large ratios of heat transfer area to volume. They can be easily cleaned
- Luas Perpindahan Panas > 120ft^2
- Panjang pipe = 12,16, 20 ft

Kriteria yang harus dipenuhi oleh alat pemindah panas:

- ✓ Pressure drop masing-masing aliran tidak melebihi batas yang ditetapkan, yaitu:
  Maksimal 10 psi, untuk aliran fluida
  Maksimal 1,5 - 2 psi, untuk aliran gas atau uap
- ✓ Mampu memindahkan panas sesuai kebutuhan proses pada keadaan kotor yang dinyatakan dalam dirt factor (Rd) dengan ketentuan sebagai berikut:
  Rd hitung = Rd ketetapan, desain baik sekali
  Rd hitung > 5 s/d 10% Rd ketentuan, desain dapat diterima
  Rd hitung >> Rd ketentuan, desain tidak dapat diterima (*over design*)
  Rd hitung < Rd ketentuan, desain tidak dapar diterima (*under design*)

Double – pipe Heat Exchanger

CALCULATION DPHE

Data yang diketahui:

- Hot Fluid $T_{in} = T_1$
  $T_{out} = T_2$
- Cold Fluid $T_{in} = t_1$
  $T_{out} = t_2$

Catat laju massa fluida panas dan laju massa fluida dingin (M)

1. Mencari property dari fluida (fluida dingin dan fluida panas)
   - A. Mencari T_{av}

$$Cold\ fluid = t_{av} = \frac{t_1 + t_2}{2}$$

$$Hot\ fluid = T_{av} = \frac{T_2 + T_1}{2}$$

   - B. Mencari cp, k dan μ dari grafik atau tabel yang sudah disediakan
     Didapatkan dari buku Kern "Heat Transfer"

Fluida panas dan dingin

Mencari data Thermal Conductivities (k) : Tabel 2 - Tabel 5, dan Fig I

TABLE 5. THERMAL CONDUCTIVITIES OF GASES AND VAPORS.*—(*Continued*)

Substance	°F	k
Hydrogen and nitrogen	32	
0% H_2	.....	0.0133
20%	.....	0.0212
40%	.....	0.0313
60%	.....	0.0438
80%	.....	0.0635
Hydrogen and nitrous oxide	32	
0% H_2	.....	0.0002
20%	.....	0.0170
40%	.....	0.0270
60%	.....	0.0410
80%	.....	0.0650
Hydrogen sulphide	32	0.0076
Mercury	392	0.0197
Methane	−148	0.0100
	−58	0.0145
	32	0.0175
	122	0.0215
Methyl alcohol	32	0.0083
	212	0.0128
Acetate	32	0.0059
	68	0.0068
Methyl chloride	32	0.0053
	115	0.0072
	212	0.0094
	363	0.0130
	413	0.0148
Methylene chloride	32	0.0039
	115	0.0049
	212	0.0063
	413	0.0095

Substance	°F	k
Nitric oxide	−94	0.0103
	32	0.0138
Nitrogen	−148	0.0095
	32	0.0140
	122	0.0160
	212	0.0180
Nitrous oxide	−98	0.0067
	32	0.0087
	212	0.0128
Oxygen	−148	0.0095
	−58	0.0119
	32	0.0142
	122	0.0164
	212	0.0185
Pentane (*n*-)	32	0.0074
	68	0.0083
(iso-)	32	0.0072
	212	0.0127
Propane	32	0.0087
	212	0.0151
Sulphur dioxide	32	0.0050
	212	0.0069
Water vapor	115	0.0120
	212	0.0137
	392	0.0187
	572	0.0248
	752	0.0315
	932	0.0441

* From Perry, J. H., "Chemical Engineers' Handbook," 3d ed., McGraw-Hill Book Company, Inc., New York, 1950.

Tav, tav digunakan untuk cari k hot dan k cold, kalau tidak ada suhunya.. Pakai interpolasi

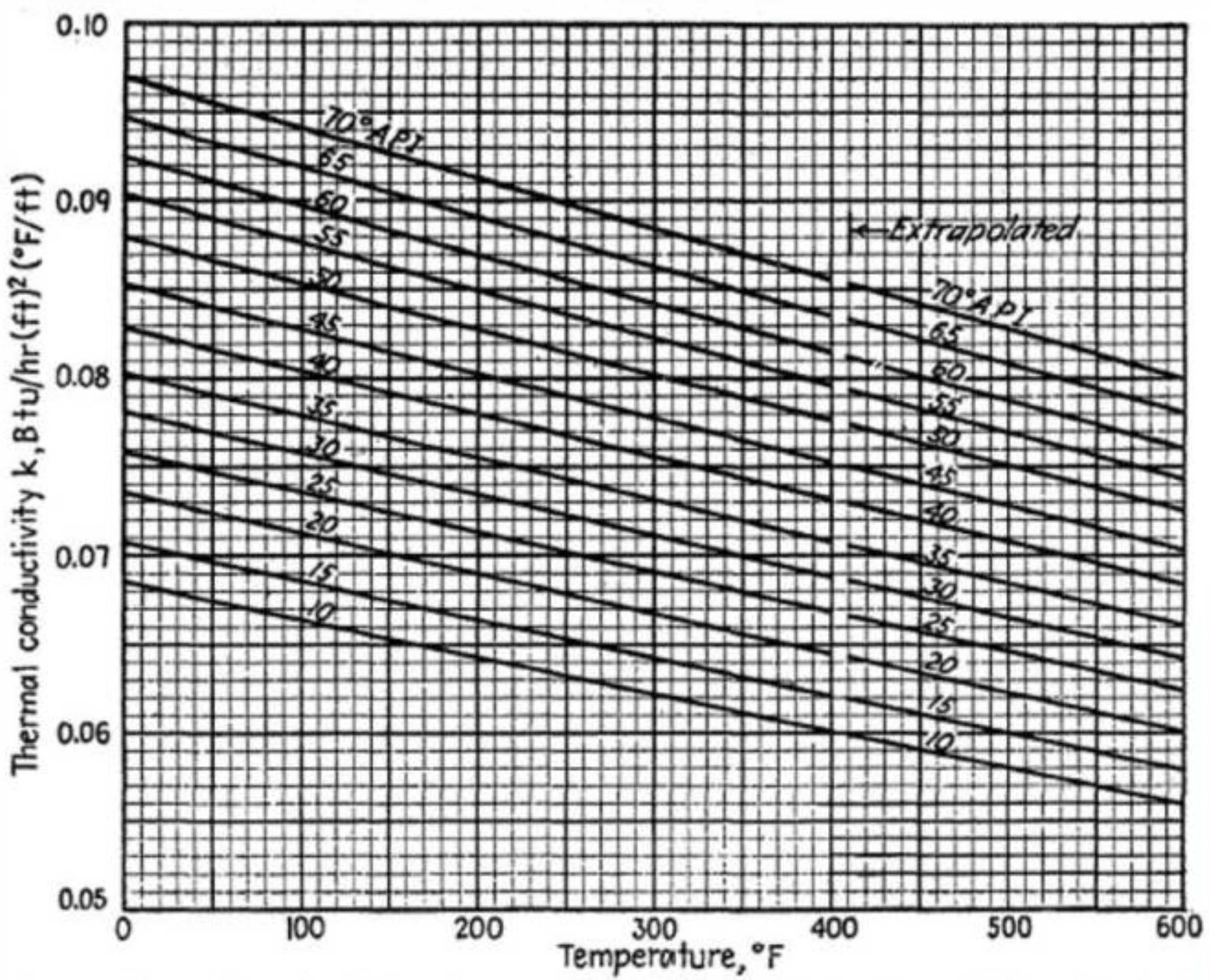


FIG. 1. Thermal conductivities of hydrocarbon liquids. (*Adapted from Natl. Bur. Standards Misc. Pub.* 97.)

Fractions from crude oil	Approx °API
Light ends and gases	114
Gasoline	75
Naphtha	60
Kerosene	45
Absorption oil	40
Straw oil	40
Distillate	35
Gas oil	28
Lube oil	18–30
Reduced crude	
Paraffin wax and jelly	
Fuel oil (residue)	25–35
Asphalt	

American Petroleum Institute (°API)

Tav, tav digunakan untuk cari k hot dan k cold. Kalau fluida dingin air so pakai table 2 –table 5

Tav = 200 dan API 60

Mencari data Specific heats of liquids (c_p) : Fig 2 - Fig 5

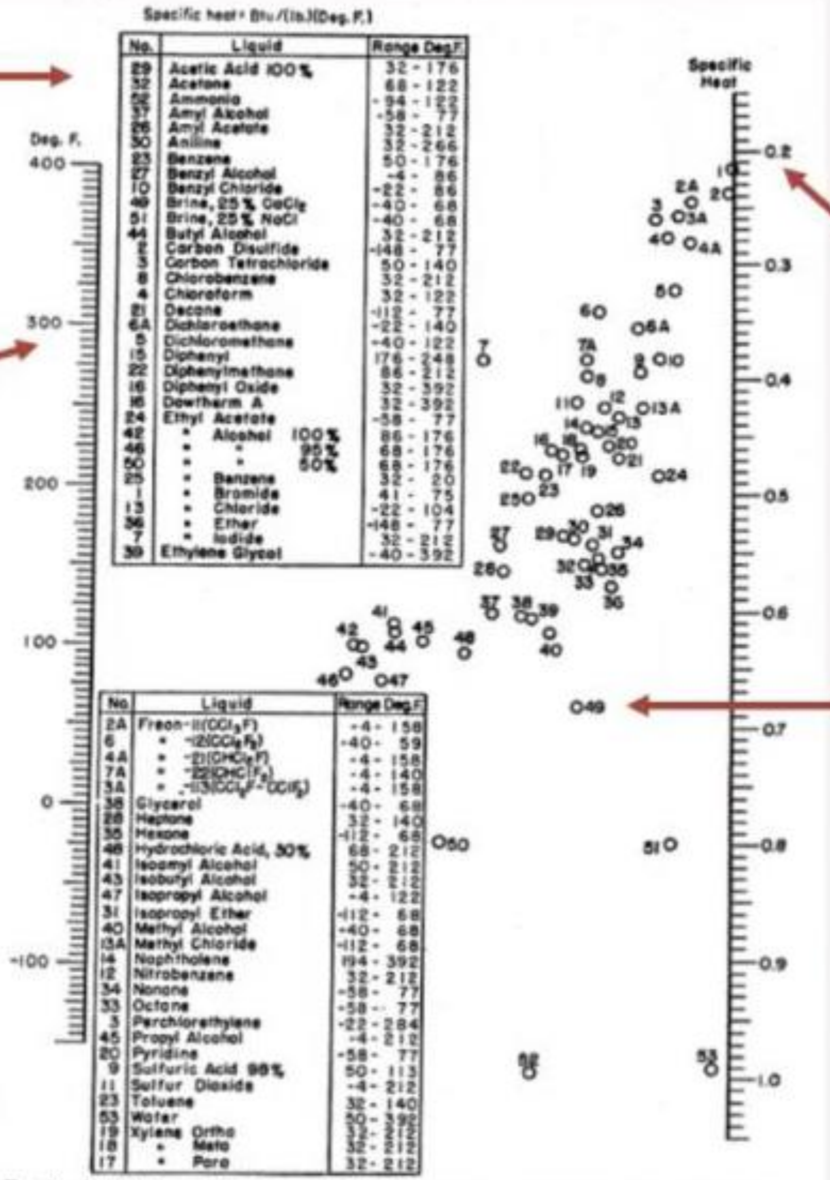
Daftar liquid dan nomor liquida

Temperatur liquid

Nilai c_p

Nomor liquida

Tav dan tav,



No.	Liquid	Range Deg. F.
29	Acetic Acid 100%	32 - 176
32	Acetone	68 - 122
52	Ammonia	-94 - 122
37	Amyl Alcohol	-58 - 77
26	Amyl Acetate	32 - 212
30	Aniline	32 - 266
23	Benzene	50 - 176
27	Benzyl Alcohol	-4 - 86
10	Benzyl Chloride	-22 - 86
49	Brine, 25% $CaCl_2$	-40 - 68
51	Brine, 25% NaCl	-40 - 68
44	Butyl Alcohol	32 - 212
2	Carbon Disulfide	-148 - 77
3	Carbon Tetrachloride	50 - 140
8	Chlorobenzene	32 - 212
4	Chloroform	32 - 122
21	Decane	-112 - 77
6A	Dichloroethane	-22 - 140
5	Dichloromethane	-40 - 122
15	Diphenyl	176 - 248
22	Diphenylmethane	86 - 212
16	Diphenyl Oxide	32 - 392
16	Dowtherm A	32 - 392
24	Ethyl Acetate	-58 - 77
42	" Alcohol 100%	86 - 176
46	" " 95%	68 - 176
50	" " 50%	68 - 176
25	" Benzene	32 - 20
1	" Bromide	41 - 75
13	" Chloride	-22 - 104
36	" Ether	-148 - 77
7	" Iodide	32 - 212
39	Ethylene Glycol	-40 - 392

No.	Liquid	Range Deg. F.
2A	Freon-11(CCl_3F)	-4 - 158
6	" -12(CCl_2F_2)	-40 - 59
4A	" -21($CHCl_2F$)	-4 - 158
7A	" -22($CHClF_2$)	-4 - 140
3A	" -113(CCl_2F-$CClF_2$)	-4 - 158
38	Glycerol	-40 - 68
28	Heptane	32 - 140
35	Hexane	-112 - 68
48	Hydrochloric Acid, 30%	68 - 212
41	Isoamyl Alcohol	50 - 212
43	Isobutyl Alcohol	32 - 212
47	Isopropyl Alcohol	-4 - 122
31	Isopropyl Ether	-112 - 68
40	Methyl Alcohol	-40 - 68
13A	Methyl Chloride	-112 - 68
14	Naphthalene	194 - 392
12	Nitrobenzene	32 - 212
34	Nonane	-58 - 77
33	Octane	-58 - 77
3	Perchlorethylene	-22 - 284
45	Propyl Alcohol	-4 - 212
20	Pyridine	-58 - 77
9	Sulfuric Acid 98%	50 - 113
11	Sulfur Dioxide	-4 - 212
23	Toluene	32 - 140
53	Water	50 - 392
19	Xylene Ortho	32 - 212
18	" Meta	32 - 212
17	" Para	32 - 212

FIG. 2. Specific heats of liquids. (*Chilton, Colburn, and Vernon, based mainly on data from International Critical Tables. Perry, "Chemical Engineers' Handbook," 3d ed., McGraw-Hill Book Company, Inc., New York,* 1950.)

Specific heats of hydrocarbon liquids (c_p)

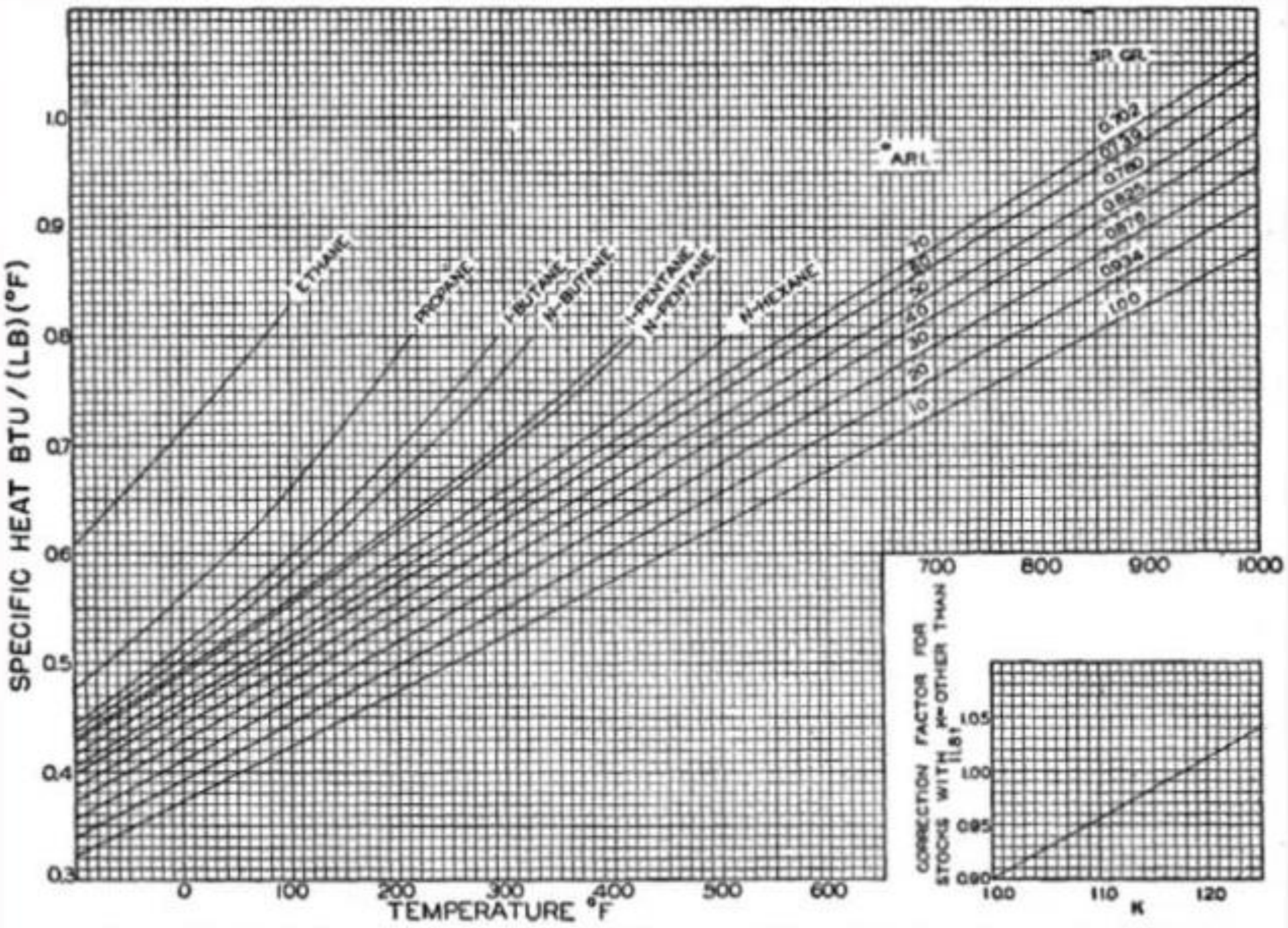


FIG. 4. Specific heats of hydrocarbon liquids. [*Holcomb and Brown, Ind. Eng. Chem.*, **34**, 595 (1942).]

† K = characterization factor.

Mencari data Viscosities of Liquids (μ) : Tabel hal 821, 822, 824 ; Fig 14 - Fig 15

VISCOSITIES OF PETROLEUM FRACTIONS
For temperature ranges employed in the text
Coordinates to be used with Fig. 14

	X	Y
76°API natural gasoline	14.4	6.4
56°API gasoline	14.0	10.5
42°API kerosene	11.6	16.0
35°API distillate	10.0	20.0
34°API mid-continent crude	10.3	21.3
28°API gas oil	10.0	23.6

VISCOSITIES OF LIQUIDS*
Coordinates to be used with Fig. 14

Liquid	X	Y	Liquid	X	Y
Acetaldehyde	15.2	4.8	Freon-21	15.7	7.5
Acetic acid, 100%	12.1	14.2	Freon-22	17.2	4.7
Acetic acid, 70%	9.5	17.0	Freon-113	12.5	11.4
Acetic anhydride	12.7	12.8	Freon-114	14.6	8.3
Acetone, 100%	14.5	7.2	Glycerol, 100%	2.0	30.0
Acetone, 35%	7.9	15.0	Glycerol, 50%	6.9	19.6
Allyl alcohol	10.2	14.3	Heptane	14.1	8.4
Ammonia, 100%	12.6	2.0	Hexane	14.7	7.0
Ammonia, 26%	10.1	13.9	Hydrochloric acid, 31.5%	13.0	16.6
Amyl acetate	11.8	12.5	Isobutyl alcohol	7.1	18.0
Amyl alcohol	7.5	18.4	Isobutyric acid	12.2	14.4

Catat nilai X dan Y untuk membaca figure 14-15

21:30

56 ° API Gasoline

X = 14.0

Y = 10.5

Tav dan tav

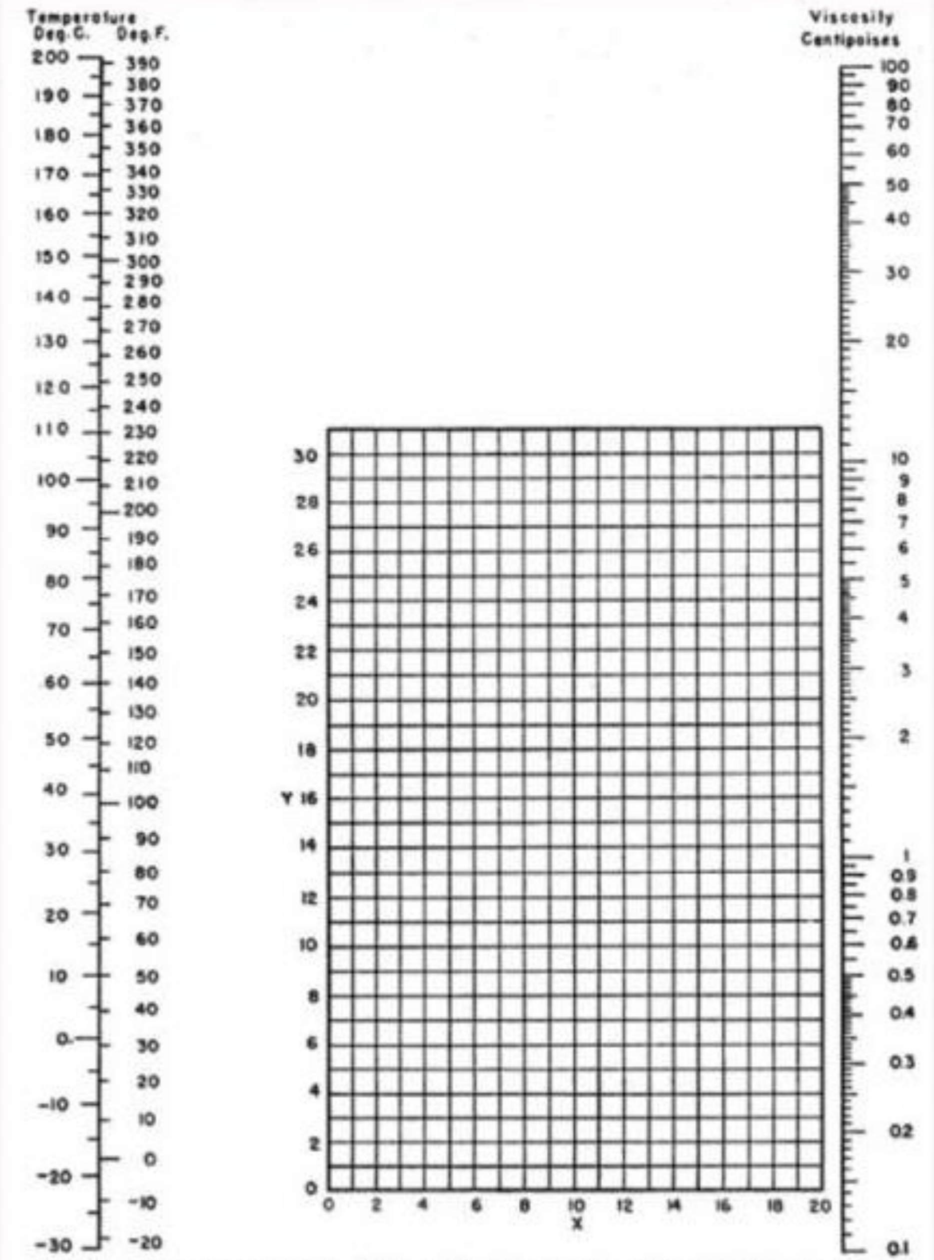


Fig. 14. Viscosities of liquids. (*Perry, "Chemical Engineers' Handbook," 3d ed., McGraw Hill Book Company, Inc., New York,* 1950.)

2 Heat balance (untuk mendapatkan massa fluida dan Q)

➡ Massa hot fluid atau cold fluid wajib diketahui.
λ : fig 12 atau table 7

$$Q = m \times c_p \times \Delta T = m \times \lambda$$

Q1 = Q2 = Q hot = Q cold, misal Fluida panas berubah fasa (steam) >> laten, kalau perubahan hanya suhu maka pakai panas sensible

Qhot = Q cold

$m \times \lambda$ = $m \times c_p \times \Delta T$

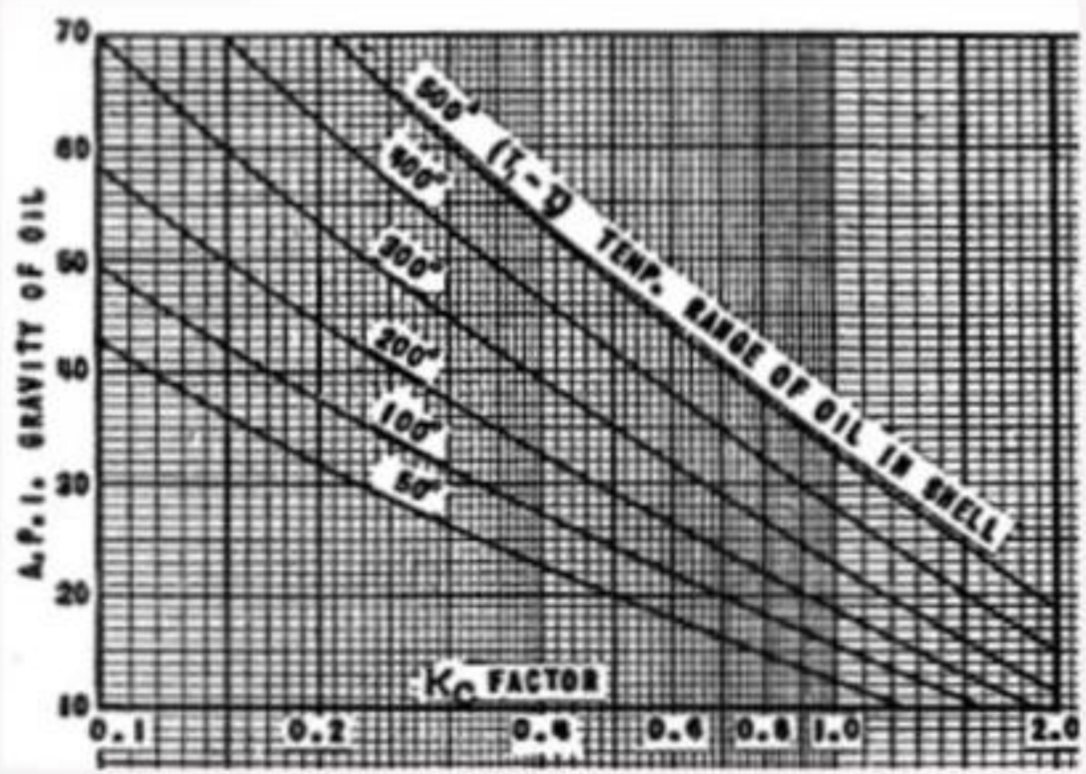
3 Menghitung LMTD

Hot Fluid		Cold Fluid	Diff	
160 (T_1)	Higher Temp	120 (t_2)	40	Δt_2
100 (T_2)	Lower Temp	80 (t_1)	20	Δt_1
			20	$\Delta t_2 - \Delta t_1$

$$\Delta_{t\ LMTD} = \frac{\Delta t_2 - \Delta t_1}{2{,}3 \log\left(\frac{\Delta t_2}{\Delta t_1}\right)}$$

4 Caloric Temperature

A. Mencari nilai Kc dengan grafik pada Fig 17



3 Menghitung LMTD

Hot Fluid		Cold Fluid	Diff	
160 (T_1)	Higher Temp	120 (t_2)	40	Δt_2
100 (T_2)	Lower Temp	80 (t_1)	20	Δt_1
			20	Δt_2-Δt_1

$$\Delta_{t\ LMTD} = \frac{\Delta t_2 - \Delta t_1}{2{,}3 \log\left(\frac{\Delta t_2}{\Delta t_1}\right)}$$

B. Menghitung $\Delta t_c/\Delta t_h$ $= \frac{\Delta t1}{\Delta t2}$

C. Mencari nilai Fc dengan bantuan grafik pada Fig 17

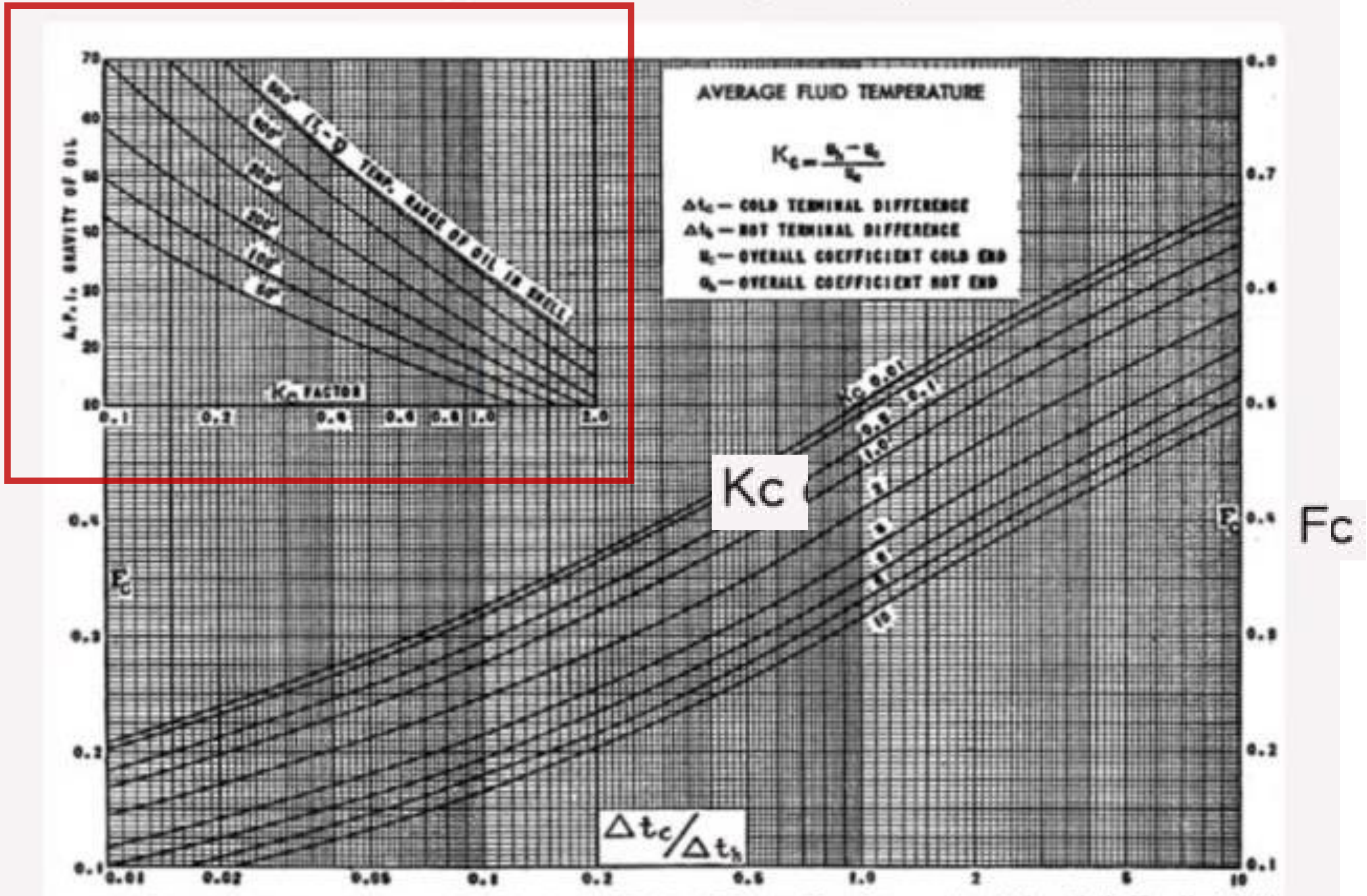


Fig. 17. The caloric temperature factor F_c. (Standards of Tubular Exchanger Manufacturers Association, 2d ed., New York, 1949.)

D. Menghitung Caloric Temperature

$$T_c = T_2 + F_c(T_1 - T_2)$$
$$t_c = t_1 + F_c(t_2 - t_1)$$

PERANCANGAN ALAT PROSES

Heat Exchanger 2

Oleh : Indah Prihatiningtyas D.S

Menentukan ukuran DPHE dengan trial

5 Trial ukuran DPHE

Ukuran DPHE (in)	Flow Area (in^2)		Diameter eqivalen anulus (in)	
	Anulus	Pipe	de	de'
2 x 1 ¼	1,19	1,50	0,915	0,40
2 ½ x 1 ¼	2,63	1,50	2,020	0,81
3 x 2	2,93	3,35	1,570	0,69
4 x 3	3,14	7,38	1,14	0,53

↓ a_{an}

Dicatat dan satuannya dibawa ke ft

Trial 1:

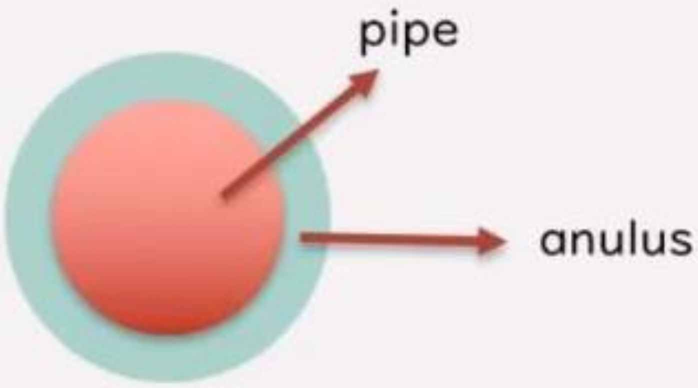
Ukuran DPHE	3 x 2			
a_{an}	2,93	in^2	0,020347	ft^2
d_e	1,57	in	0,130781	ft
d_e'	0,69	in	0,057477	ft

Kalau ukuran DPHE adalah 3 x 2, maka Internal pipe size atau IPS adalah 2

Nominal Pipe Size (IPS)	Diameter luar (do)	Nomor Schedule	Diameter dalam (di)	Flow Area	Luas / satuan panjang (ft^2/ft)	
(in)	(in)		(in)	(in^2)	Dalam	Luar
1 1/4	1,66	40	1,38	1,5	0,345	0,362
		80	1,278	1,28		0,335
2	2,38	40	2,067	3,35	0,622	0,542
		80	1,939	2,95		0,508
2 1/2	2,88	40	2,469	4,79	0,753	0,647
		80	2,323	4,23		0,609
3	3,5	40	3,068	7,38	0,917	0,804
		80	2,9	6,61		0,76
4	4,5	40	4,026	12,7	1,178	1,055
		80	3,826	11,5		1,002

d_{op} d_{ip} a_p a''

6 Evaluasi Perpindahan Panas



Anulus	Pipe
A. Menghitung N_{re} $N_{Re} = \frac{G_{an} \times d_e}{\mu \times 2{,}42}$ $G_{an} = \frac{m}{a_{an}}$	A. Menghitung N_{re} $N_{Re} = \frac{G_{ap} \times d_i}{\mu \times 2{,}42}$ $G_{ap} = \frac{m}{a_p}$
B. Mencari faktor panas J_H dari Fig 24	B. Mencari faktor panas J_H dari Fig 24

Laju massa yang cepat di dalam pipe, yg lambat di anulus

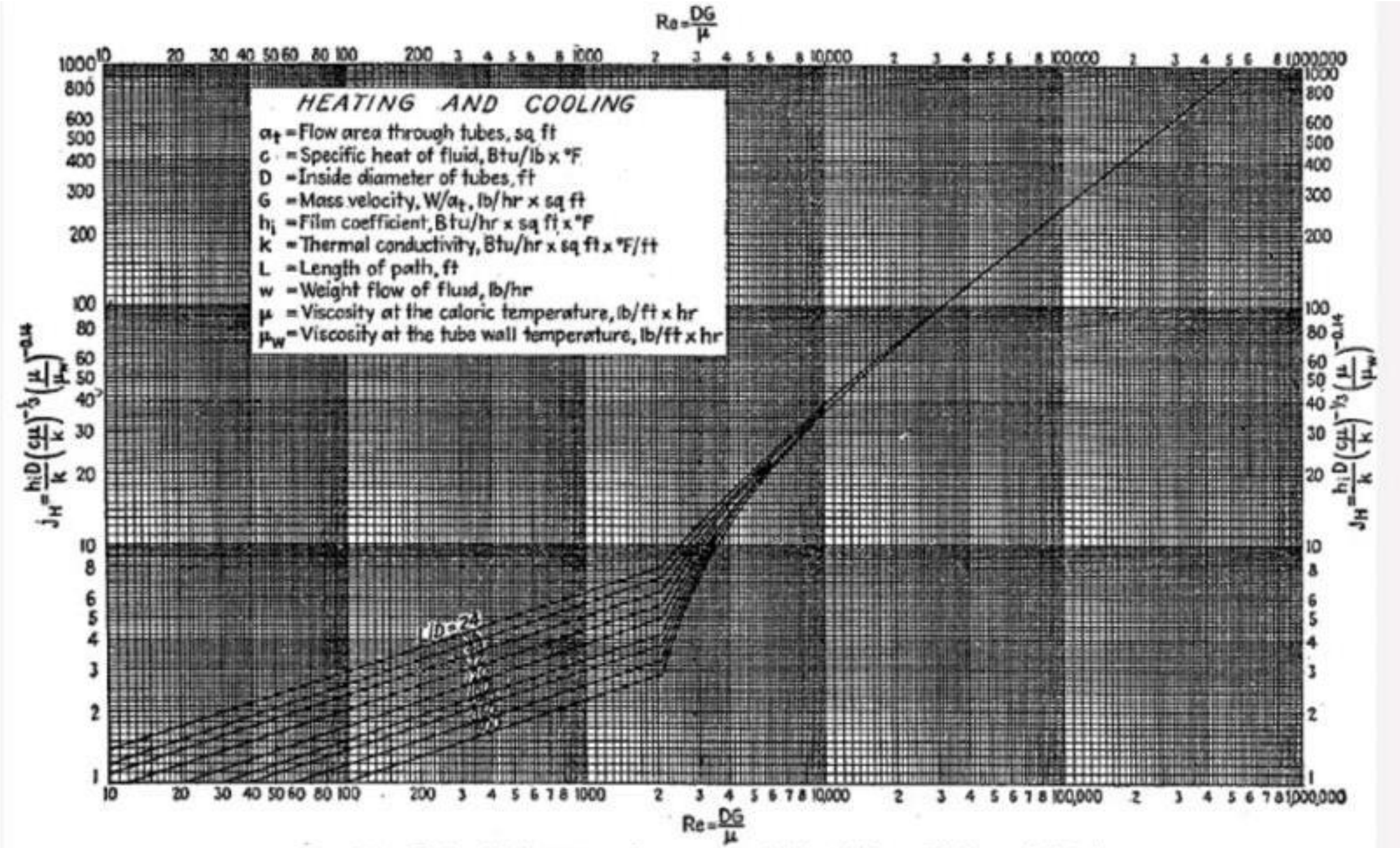


FIG. 24. Tube-side heat-transfer curve. *(Adapted from Sieder and Tate.)*

Cek satuan JH

Anulus	Pipe
C. Menghitung $\left(\frac{c_p\mu}{k}\right)^{1/3}$	C. Menghitung $\left(\frac{c_p\mu}{k}\right)^{1/3}$
D. Menghitung koefisien perpindahan panas $h_o = J_H \times \frac{k}{D_e} \times \left(\frac{C_p\mu}{k}\right)^{1/3} \times \left(\frac{\mu}{\mu_w}\right)^{0,14}$	D. Menghitung koefisien perpindahan panas $h_i = J_H \times \frac{k}{D} \times \left(\frac{C_p\mu}{k}\right)^{1/3} \times \left(\frac{\mu}{\mu_w}\right)^{0,14}$ $h_{io} = h_i \times \frac{ID}{OD}$

Note: $\left(\frac{\mu}{\mu_w}\right)^{0,14} = \phi$ Dapat dianggap = 1, jika liquida memiliki viskositas ≤1 centipoise

ΦA (annulus) dan Φp (pipa)

Namun, jika liquida memiliki viskositas ≥ 1 centipoise, maka μ_w dapat dihitung dari t_w

t_w = the pipe wall temperature

When cold fluid inside the pipe:

$$t_w = t_c + \frac{h_o}{h_{io} + h_o}(T_c - t_c)$$

When hot fluid inside the pipe:

$$t_w = t_c + \frac{h_{io}}{h_{io} + h_o}(T_c - t_c)$$

Gunakan untuk mencari μ_w sebagai nilai viskocitas pada tube wall temperature

Hitung tw, ho dan hio belum diketahui??? >>>> pakai perbandingan

$$\left(\frac{\mu}{\mu_w}\right)^{0,14} = \phi$$

$$h_i = J_H \times \frac{k}{D} \times \left(\frac{C_p\mu}{k}\right)^{1/3} \times \left(\frac{\mu}{\mu_w}\right)^{0,14}$$

misal

$\frac{h_i}{\phi_p}$	44,04328193	$\frac{h_{io}}{\phi_p}$	38,25103519

Hitung hi lalu cari hio dengan perbandingan

$$h_{io} = h_i \times \frac{ID}{OD}$$

7 Menghitung Clean Overall Coefficient (U_C)

$$U_c = \frac{h_o \times h_{io}}{h_o + h_{io}}$$

8 Menghitung Design Overall Coefficient (U_D)

$$\frac{1}{U_D} = \frac{1}{U_C} + R_{d\,min}$$

R_D ditentukan di soal (diketahui)

9 Menghitung Required Surface and Required Length

- Required Surface

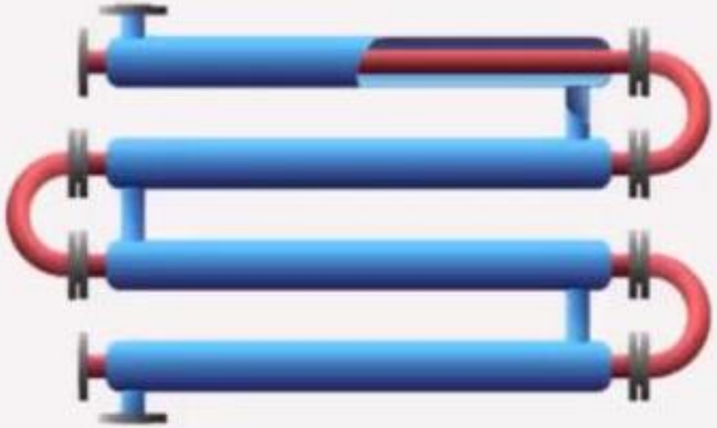
$$A = \frac{Q}{U_D \times \Delta t_{LMTD}}$$

- Required Length

$$L = \frac{A}{a''}$$

a''= outside surface

Panjang pipa (ft)	Hairpin (buah)	Pembulatan hair pin (buah)	L baru (ft)
12	4,6	5	120
15	3,5	4	120
20	2,78	3	120



10 Menentukan Actual Design

$$A_{actual} = L_{baru} \times a''$$

$$U_{D\ actual} = \frac{Q}{A_{act} \times \Delta t_{LMTD}}$$

$$R_D = \frac{U_C - U_D}{U_C U_D}$$

pastikan R_d hitung = R_d yang ditentukan ATAU R_d hitung > R_d yang ditentukan dengan range 5 - 10%

Kriteria yang harus dipenuhi oleh alat pemindah panas:

- ✓ Pressure drop masing-masing aliran tidak melebihi batas yang ditetapkan, yaitu:
  Maksimal 10 psi, untuk aliran fluida
  Maksimal 1,5 - 2 psi, untuk aliran gas atau uap
- ✓ Mampu memindahkan panas sesuai kebutuhan proses pada keadaan kotor yang dinyatakan dalam dirt factor (Rd) dengan ketentuan sebagai berikut:
  Rd hitung = Rd ketetapan, desain baik sekali
  Rd hitung > 5 s/d 10% Rd ketentuan, desain dapat diterima
  Rd hitung >> Rd ketentuan, desain tidak dapat diterima (*over design*)
  Rd hitung < Rd ketentuan, desain tidak dapar diterima (*under design*)

11 Menghitung Pressure Drop (ΔP)

Anulus	Pipa
A. Menghitung N_{re} $N_{Re} = \frac{G_{an} \times d_e'}{\mu \times 2{,}42}$ $G_{an} = \frac{m}{a_{an}}$	A. Menghitung N_{re} $N_{Re} = \frac{G_{ap} \times d_i}{\mu \times 2{,}42}$ $G_{an} = \frac{m}{a_p}$
B. Menghitung friksi $f = 0{,}0035 + \frac{0{,}264}{(N_{Re}^{0{,}42})}$	B. Menghitung friksi $f = 0{,}0035 + \frac{0{,}264}{(N_{Re}^{0{,}42})}$

Kriteria yang harus dipenuhi oleh alat pemindah panas:

✓ Pressure drop masing-masing aliran tidak melebihi batas yang ditetapkan, yaitu:
Maksimal 10 psi, untuk aliran fluida
Maksimal 1,5 - 2 psi, untuk aliran gas atau uap

✓ Mampu memindahkan panas sesuai kebutuhan proses pada keadaan kotor yang dinyatakan dalam dirt factor (Rd) dengan ketentuan sebagai berikut:
Rd hitung = Rd ketetapan, desain baik sekali
Rd hitung > 5 s/d 10% Rd ketentuan, desain dapat diterima
Rd hitung >> Rd ketentuan, desain tidak dapat diterima (*over design*)
Rd hitung < Rd ketentuan, desain tidak dapar diterima (*under design*)

Anulus	Pipa
C. Menghitung densitas fluida dengan bantuan specific gravity C.1. Cari specific gravity (s) dari Tabel 6 C.2. Cari ρ fluida dengan cara $s = \frac{\rho_{fluida}}{\rho_{air}}$	C. Menghitung densitas fluida dengan bantuan specific gravity C.1. Cari specific gravity (s) dari Tabel 6 C.2. Cari ρ fluida dengan cara $s = \frac{\rho_{fluida}}{\rho_{air}}$

Anulus	Pipa
D. Mencari ΔP karena Panjang Anulus $\Delta Fa = \frac{4 \times f \times G_{an}^2 \times L}{2 \times g \times \rho^2 \times d_e{'}}$ $F_t = n\left(\frac{v^2}{2g}\right)$ Dimana: $v = \frac{G_{an}}{3600\rho}$ n = jumlah hairpin	D. Mencari ΔP karena Panjang pipa $\Delta Fp = \frac{4 \times f \times G_p^2 \times L}{2 \times g \times \rho^2 \times d_i}$ $\Delta P_p = \frac{\Delta F_p \times \rho}{144}$ $\Delta p_p < 2\ psi, maka\ OK$ jika gas/uap
E. Mencari Δp total anulus $\Delta P_a = \frac{(\Delta F_a + F_t) \times \rho}{144}$ $\Delta p_a < 10\ psi = OK$ jika liquida	

TABLE 6. SPECIFIC GRAVITIES AND MOLECULAR WEIGHTS OF LIQUIDS

Compound	Mol. wt.	s*	Compound	Mol. wt.	s*
Acetaldehyde	44.1	0.78	Ethyl iodide	155.9	1.93
Acetic acid, 100%	60.1	1.05	Ethyl glycol	88.1	1.04
Acetic acid, 70%	......	1.07	Formic acid	46.0	1.22
Acetic anhydride	102.1	1.08	Glycerol, 100%	92.1	1.26
Acetone	58.1	0.79	Glycerol, 50%	......	1.13
Allyl alcohol	58.1	0.86	*n*-Heptane	100.2	0.68
Ammonia, 100%	17.0	0.61	*n*-Hexane	86.1	0.66
Ammonia, 26%	......	0.91	Isopropyl alcohol	60.1	0.79
Amyl acetate	130.2	0.88	Mercury	200.6	13.55
Amyl alcohol	88.2	0.81	Methanol, 100%	32.5	0.79
Aniline	93.1	1.02	Methanol, 90%	......	0.82
Anisole	108.1	0.99	Methanol, 40%	......	0.94
Arsenic trichloride	181.3	2.16	Methyl acetate	74.9	0.93
Benzene	78.1	0.88	Methyl chloride	50.5	0.92
Brine, $CaCl_2$ 25%	......	1.23	Methyl ethyl ketone	72.1	0.81
Brine, NaCl 25%	......	1.19	Naphthalene	128.1	1.14
Bromotoluene, ortho	171.0	1.42	Nitric acid, 95%	......	1.50
Bromotoluene, meta	171.0	1.41	Nitric acid, 60%	......	1.38
Bromotoluene, para	171.0	1.39	Nitrobenzene	123.1	1.20
n-Butane	58.1	0.60	Nitrotoluene, ortho	137.1	1.16
i-Butane	58.1	0.60	Nitrotoluene, meta	137.1	1.16
Butyl acetate	116.2	0.88	Nitrotoluene, para	137.1	1.29
n-Butyl alcohol	74.1	0.81	*n*-Octane	114.2	0.70
i-Butyl alcohol	74.1	0.82	Octyl alcohol	130.23	0.82
n-Butyric acid	88.1	0.96	Pentachloroethane	202.3	1.67
i-Butyric acid	88.1	0.96	*n*-Pentane	72.1	0.63
Carbon dioxide	44.0	1.29	Phenol	94.1	1.07
Carbon disulfide	76.1	1.26	Phosphorus tribromide	270.8	2.85
Carbon tetrachloride	153.8	1.60	Phosphorus trichloride	137.4	1.57
Chlorobenzene	112.6	1.11	Propane	44.1	0.59
Chloroform	119.4	1.49	Propionic acid	74.1	0.99
Chlorosulfonic acid	116.5	1.77	*n*-Propyl alcohol	60.1	0.80
Chlorotoluene, ortho	126.6	1.08	*n*-Propyl bromide	123.0	1.35
Chlorotoluene, meta	126.6	1.07	*n*-Propyl chloride	78.5	0.89
Chlorotoluene, para	126.6	1.07	*n*-Propyl iodide	170.0	1.75
Cresol, meta	108.1	1.03	Sodium	23.0	0.97
Cyclohexanol	100.2	0.96	Sodium hydroxide, 50%	......	1.53
Dibromo methane	187.9	2.09	Stannic chloride	260.5	2.23
Dichloro ethane	99.0	1.17	Sulfur dioxide	64.1	1.38
Dichloro methane	88.9	1.34	Sulfuric acid, 100%	98.1	1.83
Diethyl oxalate	146.1	1.08	Sulfuric acid, 98%	......	1.84
Dimethyl oxalate	118.1	1.42	Sulfuric acid, 60%	......	1.50
Diphenyl	154.2	0.99	Sulfuryl chloride	135.0	1.67
Dipropyl oxalate	174.1	1.02	Tetra chloroethane	167.9	1.60
Ethyl acetate	88.1	0.90	Tetra chloroethylene	165.9	1.63
Ethyl alcohol, 100%	46.1	0.79	Titanium tetrachloride	189.7	1.73
Ethyl alcohol, 95%	......	0.81	Toluene	92.1	0.87
Ethyl alcohol, 40%	......	0.94	Trichloroethylene	131.4	1.46
Ethyl benzene	106.1	0.87	Vinyl acetate	86.1	0.93
Ethyl bromide	108.9	1.43	Water	18.0	1.0
Ethyl chloride	64.5	0.92	Xylene, ortho	106.1	0.87
Ethyl ether	74.1	0.71	Xylene, meta	106.1	0.86
Ethyl formate	74.1	0.92	Xylene, para	106.1	0.86

* At approximately 68°F. These values will be satisfactory, without extrapolation, for most engineering problems.

- Kalau Rd dan ΔP tidak sesuai dengan kriteria maka ulangi dari perkiran ukuran DPHE