LAMPIRAN A

PERANCANGAN REAKTOR

Fungsi : Mereaksikan larutan sodium karbonat (Na_2CO_3) dengan karbon dioksida (CO_2) agar membentuk sodium bikarbonat ($NaHCO_3$) sebagai produk utama dan air sebagai hasil samping.

Jenis : Reaktor gelembung (*Bubble column reactor*) silinder tegak dan tangki tertutup.

Kondisi operasi : T = 40 °C

P = 3 atm

Reaksi yang terjadi adalah :

- Reaksi utama :

$$Na_2CO_{3(s)} + H_2O_{(l)} + CO_{2(g)} \longrightarrow NaHCO_{3(s)}$$

Sodium karbonat + Air + Karbon dioksida Sodium bikarbonat

Alasan pemilihan *bubble reactor* :

a. Reaktor gelembung cocok untuk reaksi gas-cair, dengan jumlah gas yang relatif sedikit direaksikan dengan cairan yang jumlahnya besar.
b. Relatif lebih murah, perawatan dan pengoperasiannya lebih mudah.
c. Di dalam reaktor gelembung, aliran gas dianggap *plug flow*, tetapi cairan teraduk sempurna oleh aliran gelembung gas yang naik ke atas, sehingga suhu cairan didalam reaktor selalu serba sama (*mixed flow*).

(Perry’s, 23 – 49, 1999)

1. **Umpan Cairan**

Komposisi umpan cairan masuk reaktor

T = 40 ^oC

P = 3 atm

Komponen	Kg/Jam	wi	Kmol/jam	xi
Na_2CO_3	5332,519	0,200	50,307	0,041
H_2O	21383,508	0,800	1187,973	0,959
Total	26716,027	1,000	1238,279	1,000

Densitas cairan

$$\rho = A * B^{-\left(1-\frac{T}{Tc}\right)^n}$$

Komponen	Wi	A	B	n	Tc (K)	ρ (kg/m³)	ρc = wi*ρ
Na_2CO_3	0,200					2540,0000	506,9840
H_2O	0,800	0,3471	0,2740	0,2857	647,1300	1013,6381	811,3160
Total	1,000					3553,6381	1318,3000

$\rho_{campuran}$ = 1.318,3000 kg/m^3 = 82,2248 lb/ft^3

Berat molekul cairan

Komponen	BM	xi	BMc = Bmi * xi
Na_2CO_3	106	0,041	4,306
H_2O	18	0,959	17,269
Total		1,000	21,575

BMc = 21,575 kg/kmol

Kecepatan volumetris cairan :

$$Fc = \frac{\text{Massa cairan}}{\rho c}$$

$= 20,266\ m^3/jam$

Viskositas cairan

$$\log \mu = A + \frac{B}{T} + CT + DT^2$$

Komponen	Wi	A	B	C	D	log µ	µ cair	μ_{ci} = wi/µ
Na_2CO_3	0,200							
H_2O	0,800	-10,2158	1,792,5	0,0177	-0,000012	-0,1782	0,663	1,206
Total	1,000							1,206

$$\mu = \frac{1}{\mu_c}$$

= 0,8289 cP

= 8,289E-04 kg/m.s

Surface tension (σ)

$$\sigma = A\left(1 - \frac{T}{T_C}\right)^n$$

Komponen	Wi	A	Tc	n	ói	óc
Na_2CO_3	0,200					
H_2O	0,800	132,674	647,130	0,9550	70,541	56,461
$NaHCO_3$	0,000					
Total	1,000					56,461

$\sigma_{campuran}$ = 56,461 dyne/cm

= 0,0565 N/m

= 0,0058 kg/m.s^2

2. Feed Gas

Densitas

Diketahui :

P = 3,0398 bar = 3 atm

R = 0,08206 atm.m^3/mol.K

T = 313,15 K

Bm = 44 g/mol

Tc = 87,89 ^{o}F = 304,2 K

Pc = 1.070,6 psia = 73,8153 bar

Densitas gas CO2 dapat diketahui dengan persamaan berikut :

$$\rho_{\text{gas}} = \frac{\text{P } \Sigma \text{yi. BMi}}{\text{Z. R. T}}$$

Untuk mencari nilai Z perlu diketahui :

$$\text{Tr} = \frac{\text{T}}{\text{Tc}} = \frac{313,15}{304,2} = 1,02942$$

$$\text{Pr} = \frac{P}{Pc} = \frac{3,0398}{73,8153} = 0,04118$$

Dari grafik diperoleh nilai Z = 0,74

Maka densitas gas adalah

$$\rho_{\text{gas}} = \frac{3 \text{ atm x } 44 \frac{\text{g}}{\text{mol}}}{0,74 \text{ x } 0,08206 \frac{\text{L. atm}}{\text{mol. K}} \text{ x } 313,15\text{K}}$$

$$= 6,9416$$

Viskositas

Viskositas dapat dihitung dengan persamaan :

$\mu = A + BT + CT^2$ (Carl L.Yaws, P.452)

Dimana : T : Temperatut (K)

A, B dan C : Konstanta

μ_{gas} : Viskositas gas (micropoise)

Diketahui umpan masuk reaktor pada T = 40 ^oC = 313.15 K, sehingga :

Komponen	A	B	C
CO2	11,336	0,49918	-0,00010876

Maka, μ_{gas} = 156,9889 micropoise

= 1,57E-04 cP

= 1,57E-07 kg/m.s

3. Penentuan Parameter Konversi

a. Mencari persamaan laju reaksi

Dari Hari Asriyanto, 2010 :

X_A = Konversi = 98%

T = 60 menit

Reaksi :

$$Na_2CO_{3(s)} + H_2O_{(l)} + CO_{2(g)} \longrightarrow NaHCO_{3(s)}$$

A B C

Komposisi reaktan dihitung menggunakan persamaan :

$$C_x = \frac{N_x}{N_T} \text{x} \frac{P}{R.T}$$ (Fogler, 1999)

Keterangan :

C_x	= Komposisi reaktan	
N_x	= Mol reaktan	
N_T	= Mol total	= 1.238,279 Kmol
P	= Tekanan operasi	= 3 atm
T	= Temperatur operasi	= 313,15 K
R	= Konstanta gas ideal	= 0,082057 m^3.atm/Kmol.K

- **Konsentrasi Na_2CO_3**
  - $C_{AO} = \frac{50,307}{1238,279} x \frac{3}{82,057x10^{-3}x313,15}$

    $= 4,74E\text{-}03$ kmol/m^3
  - $C_A = C_{AO}(1 - X)$

    $C_A = 4,74E - 03(1 - 0,98)$

    $= 9,49E\text{-}05$ kmol/m^3

- **Konsentrasi CO_2**
  - $C_{B0} = \frac{60,718}{1238,279} x \frac{3}{82,057x10^{-3}\ x\ 313,15}$

    $= 5,72E\text{-}03$ kmol/m^3
  - $C_B = C_{BO} - (C_{AO}.X)$

    $C_B = 5,72E\text{-}03 - (4,74E\text{-}03*0,98)$

    $= 1,08E\text{-}03$

Reaksi yang terjadi merupakan reaksi orde 2, dimana persamaan laju reaksinya adalah :

$$-r_A = k\ .\ C_A\ .C_B$$

Keterangan :

$-r_A$: laju reaksi

k : konstanta laju reaksi (m^3/kmol.jam)

C_i : konsentrasi masing-masing komponen (kmol/m^3)

Dengan :

$C_A = C_{A0} (1-X_A)$

$C_B = C_{B0} – (C_{A0}.X_A)$

Sehingga,

$-r_A = k.[C_{A0}(1-X_A)].[C_{B0}-(C_{A0}.X_A)]$ ….. [1]

$$\tau = C_{A0} \int_0^X \frac{dX_A}{-r_A} \quad .... \quad [2]$$

(Levenspiel 3rd ed. Page 102)

Substitusikan persamaan [1] ke [2] :

$$\tau = \frac{1}{kC_{A0}} \int_0^X \frac{dX_A}{(1 - X_A)(1.2 - X_A)}$$

$$k = \frac{1}{\tau C_{A0}} \int_0^X \frac{dX_A}{(1-X_A)(1,2-X_A)}$$

Bentuk integral pada persamaan di atas diselesaikan dengan metode *Simpson's rule*. Jika pada bentuk integral dimisalkan dengan :

$$I = \int_0^X \frac{dX_A}{(1-X_A)(1,2-X_A)}$$

Maka,

$$\int_{X_0}^{X_N} I.\ dX = \frac{\Delta X}{3}(I_0 + 4I_1 + 2I_2 + ... + 2.I_{N-2} + 4.I_{N-1} + I)$$

Dengan $\Delta X = \dfrac{0,98}{10}$

$= 0,098$

Untuk N = 10, maka :

No	Xi	Ii	Ii.koef
0	0,0000	0,8333	0,8333
1	0,0980	1,0060	4,0241
2	0,1960	1,2388	2,4777
3	0,2940	1,5634	6,2536
4	0,3920	2,0356	4,0711
5	0,4900	2,7617	11,0467
6	0,5880	3,9660	7,9320
7	0,6860	6,1959	24,7838
8	0,7840	11,1289	22,2578
9	0,8820	26,6496	106,5984
10	0,9800	227,2727	227,2727
	Total		417,551216

Jadi, $\int_{0}^{0.98} I.\ dX$ = 13,6400

Sehingga diperoleh konstanta laju reaksi (k) :

k = 2875,7656 m^3/kmol.jam

Laju reaksi dicari menggunakan persamaan :

$$-r_A = k\ .\ C_A\ .C_B$$

Dengan : k = 2,876E+03

C_{A0} = 4,74E-03

C_{B0} = 5,725E-03

X_A = 0,98

Maka nilai ($-r_A$) = 0,0016 kmol/m^3.jam

b. Diffusivitas karbon dioksida (CO_2) terlarut kedalam cairan

$$\mathcal{D}_{BL} = \frac{117{,}3x10^{-18}\ (\phi x BM)^{\frac{1}{2}} x T}{\mu_L\ x\ {V_B}^{0,6}}$$ (Coulson 1983, vol 6 : 255)

Dengan :

$\mathcal{D}_{BL}$	: Difusivitas CO_2 dalam Pelarut, m^2/s	
Φ	: Faktor disosiasi pelarut	= 2,26
BM	: Berat molekul campuran cairan, kg/kmol	= 21,575
T	: Suhu reaktor, K	= 313,15
μ	: Viskositas cairan, kg/m.s	= 8,289E-04
V_B	: Volume molal CO2 pada titik didihnya,m3/kmol	
	= 0,034 (Tabel 8.6 Coulson, 1983 hal.258)	

Maka,

$$\mathcal{D}_{BL}\ CO_2 = \frac{117{,}3x10^{-18}\ (2{,}26\ x\ 21{,}575)^{\frac{1}{2}}\ x\ 313{,}15}{(0{,}289E-04)\ x\ (0{,}034)^{0,6}}$$

$= 2{,}353E\text{-}09\ m^2/s = 8{,}47E\text{-}06\ m^2/jam$

c. Koefisien transfer massa CO_2 di fase cair

Untuk rancangan *perforated plate*

$$K_{BL} = 0{,}42 \times \left(\frac{g.\,\mu c}{\rho c}\right)^{\frac{1}{3}} \times \left(\frac{\mathcal{D}_{BL}.\,\rho c}{\mu c}\right)^{\frac{1}{2}}$$ (Froment : 726)

Maka,

$$K_{BL} = 0{,}42 \times \left[\frac{9{,}8\ x\ 8{,}289E-04}{1.318{,}3000}\right]^{\frac{1}{3}} \times \left(\frac{2{,}353E-09\ x\ 1.318{,}3000}{8{,}289E-04}\right)^{\frac{1}{2}}$$

= 4,711E-04 m/s

= 1,6959 m/jam

4. **Menentukan Bilangan Hatta (MH)**

$$M_H^2 = \frac{k_r . C_{A0} . \vartheta_{BL}}{k_{BL}^2}$$

$$= \frac{(2,876E+03)(4,74E-03)(8,47E-06)}{(1,6959)^2} = 4,0147E\text{-}5$$

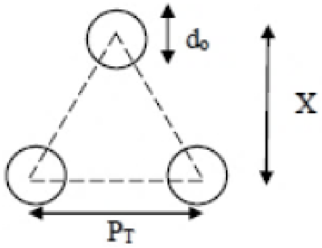
$$M_H = 0,0063$$

Nilai M_H < 0,02, sehingga reaksi kimia lebih mengontrol dibandingkan dengan transfer massa.

5. **Perancangan Perforated Plate**

Digunakan *perforated plate* dengan susunan *triangular pitch* dengan pertimbangan :

- Jumlah lubang tiap satuan lebih besar daripada susunan *square pitch*
- Ukuran reaktor menjadi lebih kecil dan turbulensi lebih terjamin



Keterangan :

P_r : Pitch

D_o : Diameter orifice

Mencari laju alir gas masuk reaktor (Q_g)

$$Qg = Mg \text{ x } \frac{1}{\rho_g} \text{ x } \frac{1}{3600}$$

$$= \left(2.671,603 \frac{kg}{jam}\right)\left(\frac{1}{6,9416\frac{kg}{m^3}}\right)\left(\frac{1}{3.600}\right)$$

$$= 0,1069 \text{ m}^3/\text{s} = 106.908,2 \text{ cm}^3/\text{s}$$

Mencari diameter gelembung (d_{bo})

$$d_{bo} = \left(\frac{6. d_o. \sigma_l}{g. (\rho_l - \rho_g)}\right)^{\frac{1}{3}}$$

Dimana :

d_{bo} : Diameter gelembung, m

d_o : Diameter orifice, m (0,024-0,95) = 0,12 cm = 0,0012 m (Perry's)

σ_L : Tegangan muka cairan, kg/m.s^2 = 0,0058

g : percepatan gravitasi, m/s^2 = 9,8

ρ : Densitas (cairan-gas), kg/m^3 = 1.318,30 dan 6,9416

Maka diameter gelembung :

$$d_{bo} = \left(\frac{6(0,0012)(0,0058)}{(9,8)(1.318,3 - 6,9416)}\right)^{\frac{1}{3}}$$

$$= 0,0015 \text{ m} \quad = 0,1477 \text{ cm}$$

Mencari laju alir tiap *orifice*

$$Q_{go} = \left(\frac{d_{bo}^3. \pi. g^{\frac{3}{5}}}{(6)(1.378)}\right)^{\frac{5}{6}}$$ (Perry's, 1999 : 14-71)

$$= \left(\frac{(0,1477)^3\left((3,14)(980)^{\frac{3}{5}}\right)}{(6)(1,378)}\right)^{\frac{5}{6}}$$

$$= 0,117 \text{ cm}^3/\text{s}$$

Mencari luas orifice

$$L_o = \frac{\pi}{4}. d_o^2$$

$$= \frac{3,14}{4}(0,12)^2$$

$$= 0,0113 \text{ cm}^2$$

Mencari jumlah orifice

$$N_o = \frac{Q_g}{Q_{go}}$$

$$= \frac{106.908,2\frac{\text{cm}^3}{\text{s}}}{0,117\frac{\text{cm}^3}{\text{s}}}$$

$$= 913.395,0963$$

Mencari nilai *pitch*

$c = k \times d_{bo}$

dimana nilai k > 1, maka diambil = 3

nilai c :

$c = (3)(0{,}1477)$

$= 0{,}4430$ cm

Mencari jumlah luas orifice

$L_{to} = L_o . N_o$

$= (0{,}0113\ cm^2)(913.395{,}0963)$

$= 10.325{,}0182\ cm^2$

Mencari luas perforated plate

Mencari persentase luas total *orifice* terhadap *perforated plate* :

$$D_{pc} = \frac{d}{c}$$

$$= \frac{0{,}12\ cm}{0{,}4430\ cm}$$

$= 0{,}2709$

diplotkan pada grafik, untuk memperoleh nilai a

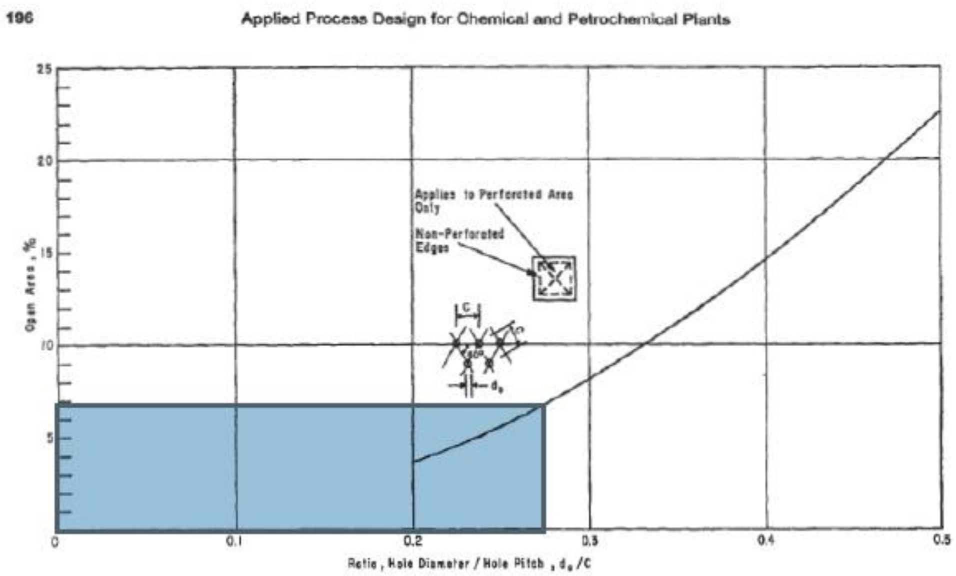


Figure 8-143. Percent open hole area for perforated and sieve trays.

dari grafik diatas, diperoleh nilai a = 6,9% = 0,0690

Maka luas *perforated plate* :

$$L_p = \frac{L_{to}}{a}$$

$$= \frac{10.325,0182\ cm^2}{0,0690}$$

$$= 149.637,9445\ cm2 \ = 14,9634\ m^2$$

6. **Menentukan Diameter dan Tinggi Cairan**

Menentukan diameter reaktor

$$D_R = \left(\frac{4. L_p}{\pi}\right)^{\frac{1}{2}}$$

$$= \left(\frac{(4)(149.637,9445)}{3,14}\right)^{\frac{1}{2}}$$

$$= 436,6023\ cm \qquad = 4,3660\ m$$

Trial tinggi reaktor

Dipilih D/H : 1 : 2

L_{R0} = H_{cair} + H_{gas} + H_{coil}

= (4,3660*2) = 8,7 m

Tekanan gas rata-rata dalam reaktor

$$P_{gr} = P + \left(\frac{0,5. \rho_L. L_{RO}}{1,0132 * 10^6}\right)$$

$$= 3 + \left(\frac{(0,5)(1.318,30)(8,7)}{(1,0132\ x\ 10^6)}\right)$$

$$= 3,0057\ atm$$

Diameter gelembung gas rata-rata dalam reaktor

$$D_{Br} = \left(\frac{d_{BO}^3. P_{gr}}{P}\right)^{\frac{1}{3}}$$

$$= \left(\frac{(0,0015)^3(3,0057)}{3}\right)^{\frac{1}{3}}$$

$$= 0,0015\ m$$

Kecepatan terminal gelembung

$$V_t = \left[\left(\frac{2.\sigma_L}{D_{Br}.\rho_L}\right) + \left(\frac{g.D_{Br}}{2}\right)\right]^{\frac{1}{2}}$$

$$= \left[\left(\frac{(2)(0{,}0058)}{(0{,}0015)(1.318{,}30)}\right) + \left(\frac{(9{,}8)(0{,}0015)}{2}\right)\right]^{\frac{1}{2}}$$

$= 0{,}1147$ m/s

Kecepatan tinggal gelembung dalam reaktor

Dengan asumsi kecepatan naik gelembung di dalam reaktor konstan pada kecepatan terminalnya.

$$\theta_g = \frac{L_{RO}}{V_t}$$

$$= \frac{8{,}7}{0{,}1147} = 76{,}1426 \text{ s}$$

Volume tiap gelembung

$$V_{go} = \frac{\pi}{6}.D_{Br}^3$$

$$= \frac{\pi}{6}(0{,}0015)^3$$

$= 1{,}6879\text{E-}09 \text{ m}^3 = 0{,}00169 \text{ m}^3$

Jumlah gelembung tiap *orifice* per satuan waktu

$$N_{go} = \frac{Q_{go}}{V_{go}}$$

$$= \frac{0{,}117}{0{,}00169}$$

$= 69$ buah

Jumlah gelembung total didalam reaktor

$$N_{gt} = N_o.Q_{go}.\theta_g$$

$$= (913.395{,}0963)(0{,}117)(76{,}1426)$$

$= 8.140.274{,}239$ buah

Volume gas gelembung total di dalam reaktor

$$V_{gt} = N_{gt}.V_{go}$$

$$= (8.140.274{,}239)(1)$$

$$= 8.140.274{,}239\ cm^3 \quad = 8{,}1403\ m^3$$

Menentukan volume cairan

Menghitung volume larutan untuk aliran *plug flow* :

$$\frac{V}{F_{A0}} = \int_0^X \frac{dX_A}{-r_A}$$

$$V = F_{A0} \int_0^{0,98} \frac{dX_A}{-r_A}$$

$$= \frac{F_{A0}}{kC_{A0}} \int_0^{0,98} \frac{dX_A}{(1 - X_A)(1{,}2 - X_A)}$$

$$= \frac{60{,}718}{(2.875{,}77 \text{ x } 4{,}74E - 03)} \text{x}(13{,}64)$$

Jadi : $V_{cair} = 60{,}7180\ m^3$

$V_{gas+cair} = V_{gas} + V_{cair}$

$= (8{,}1403 + 60{,}7180)\ m^3 \quad = 68{,}8583\ m^3$

Menentukan tinggi cairan

Diketahui :

D = 4,3660 m = 171,8903 in

$V = \frac{\pi}{4} D^2 H$ = 68,8583 m3

Maka, $H = \frac{V}{0{,}25\ .\ \pi.\ D^2}$

$= \frac{68{,}8583}{(0{,}25\ )(\pi)(4{,}3660)^2}$ = 4,6017 m = 181,1673 in

Menentukan *hold up* gas

$$\varepsilon_g = \frac{V_{gt}}{V_{gt} + V_c}$$

$$= \frac{8,1403}{8,1403 + 60,7180}$$

$$= 0,1182$$

Luas permukaan *interface*

$$A_g = \frac{6.\varepsilon_g}{D_{Br}}$$ (Perry's, 1999)

$$A_g = \frac{(6)(0,1182)}{0,00015}$$

$$= 480,0734 \text{ m}^{-1}$$

7. Penurunan Tekanan (*Pressure Drop*)

Dry pressure drop

Dry pressure drop merupakan *pressure drop* aliran gas akibat friksi di dalam hole (*orifice*). Dimana *hole* dianggap sebagai tabung pendek dengan tebal *plate* sama dengan tinggi tabung (Treyball, 1981, hal 171).

$$h_D = \frac{V_o.\rho_g}{2.g.\rho_L}.C_o\left[0,4\left(1,25 - \frac{A_0}{A_n}\right) + \frac{4.L.f}{d_o} + \left(1 - \frac{A_o}{A_n}\right)^2\right]$$

dimana :

h_D = *dry pressure drop*

V_o = kecepatan linier gas lewat *hole*, m/s

d_o = diameter *hole*, m

L = tebal *plate*

Tebal plate dari treyball, tabel 6.2, hal 169 : Untuk bahan Stainless Steel dan

d_o = 1,2 mm, maka L/d_o = 0,65

L = 0,00078 m = 0,78 mm

C_o = koefisien *orifice* = $109.\left(\frac{d_o}{L}\right)^{0.25}$ = 1,2139

A_o = luas *orifice*, m^2 = 1,13E-06

A_n = luas *perforated plate*, m^2 = 1,50E+01

ρ_L = densitas cairan, kg/m^3 = 1.318,30

Q_{go} = laju alir tiap *orifice*, m^3/s = 1,17E-07

R_{eh} = Bilangan Reynold gas lewat *hole* = 4.987,68

$$R_{eh} = \frac{V_0.\rho_g.d_o}{\mu_g}$$

f = factor friksi Fanning

= $0,079/(Re^{0,25})$, untuk aliran turbulen 2.000<Re<100.000

= 0,00940

nilai h_D :

h_D = 4,67E-05 m

Hydraulic head

Pressure drop akibat gaya hidrostastis cairan dalam reaktor (Trebal, 1981, hal 172).

h_L = tinggi cairan = 4,6017 m

Residual gas pressure drop

Pressure drop akibat pembentukan gelembung gas. (Treybal, 1981, hal 172)

$$h_R = \frac{6.\sigma_L}{\rho_L.d_o.g}$$

$$= \frac{(6)(0,0565)}{(1.318,30)(0,0012)(9,8)} = 0,0218 \text{ m}$$

***) Total pressure drop (ΔP_t)**

$h_t = h_D + h_L + h_R$

$= (4{,}67E\text{-}05)+(4{,}6017)+(0{,}0219) = 4{,}6236$ m

maka,

$\Delta P_t = h_t * \rho_L * g$

$= ((4{,}6236)(1.318{,}30)(9{,}8))/100.000$

$= 0{,}5973$ atm

8. Dimensi Reaktor

Tipe

Jenis reaktor	: Tangki tertutup, silinder tegak
Alasan pemilihan	: Proses Vessel, menjaga tekanan (P>1 atm) dan suhu tetap
Jenis *head*	: *Flanged and dished head* (*torispherical*)
Alasan pemilihan	: Cocok untuk tekanan antara 15-200 psig

Kondisi operasi

Suhu operasi	= 40 ^oC	= 313,15 K
Tekanan operasi	= 3 atm	= 44,09 psia
Tekanan total (ΔP)	= 1 atm	= 8,78 psia
Over desain	= 10%	

Pemilihan material konstruksi

Material : *Low-alloy steel SA-204 grade C*

Alasan pemilihan : 1. Tahan korosi, tahan panas dan tahan asam

2. Tekanan operasi moderat

3. Suhu operasi < 900 ^oC

4. Untuk dinding reaktor yang tebal

(Brownell, 1959 hal. 253)

Spesifikasi : *Tensile strength* = 7.500 psi

Allowable stress (f) = 18.750 psi

Corrosion allowance = 0,125

(Tabel 13.1 Brownell, 1959)

Tebal shell

$$t_s = \frac{P_d . ri}{f . E - 0,6 . P_d} + c$$ (Brownell, 1959)

Dengan : t_s = Tebal *shell*, in

P_d = Tekanan desain, psia = 71,912

r_i = Jari-jari dalam reaktor, in = 85,9452

f = *Allowable stress*, psi

c = *Corrosion allowance*, psi

E = *Single welded butt joint* = 85%

sehingga,

$$t_s = \frac{(71,912)(85,9452)}{(18.750 \text{ x } 0,85) - (0,6 \text{ x } 71,912)} + 0,125$$

$$= 0,5138 \text{ in}$$

dipilih tebal *shell* standar adalah 0,625 in = 0,0159 m

Tinggi *shell*

Tinggi reaktor = 4,602 m = 181,167 in

Diameter reaktor = 4,366 m = 171,890 in

Volume reaktor = 68,86 m^3

Over desain = 10% = 0,1

Volume perancangan = $(1+0,1)V_r$

= 75,7441 m3 = 2.674,88 ft 3= 476,3962 bbl

Volume reaktor (V_t) = $V_{shell} + 2V_{head}$

V_t = $(1/4 \times \pi \times D_i^2 \times H) + 2(0,000076 \times D_i^3)$

= 68,87092 m^3

$$H = \frac{V_t - 2 \times V_h}{0,25 \times 3,14 \times Di^2}$$

$$= \frac{(68,87092)-(2\times(68,86))}{(0,25)\times(3,14)\times(4,366)^2}$$

= 4,6033 m= 181,2339 in

Dimensi *head*

$OD_{shell} = ID_{shell} + 2t_s$

= (171,890 + 2(0,625)) in

= 173,1403 in

= 4,397764 m

= 4.397,764 mm

Rumus tebal *head* untuk *flanged & dished head* :

$$th = \frac{P_d.r_c.v}{2.f.E - 0.2P_d} + c$$

dengan :

t_h = Tebal *head*, in

P_d = Tekanan desain, psia = 71,912

D_i = *Inside diameter reactor*, in = 171,890

f = *Allowable stress*, in = 18,750

E = *Welded joint efficiency* = 0,85 (*single welded*)

C = *Corrosion allowance*, in = 0,125

k = a/b = (85,9452/42,9726) = 2

a = Jari-jari dalam = D_i/2 = 85,9452 in

b = kedalaman dish = a/2 = 42,9726 in

V = $(1/6)(2+k^2)$

= $(1/6)(2+2^2)$ = 1

sehingga nilai t_h :

$$th = \frac{P_d . r_c . v}{2.f.E - 0.2P_d} + c$$

$$= \frac{(71,912)\left(\frac{171,890}{2}\right)(1)}{(2 \text{ x } 18.750 \text{ x } 0,85) - (0,2 \text{ x } 71,912)}$$

= 0,3190 in

dipakai tebal standar adalah 0,375 in = 0,0095 m = 9,525 mm

maka, OD_{head} = ID + $2t_h$

= (171,890)+(2*0,375) in

= 172,6403 in

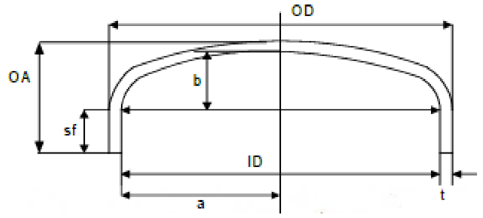
= 4,3851 m

= 4.385,064 mm

Tinggi reaktor

Dari tabel 5-11 Brownell, untuk t_h = 0,375 in diperoleh s_f = 2-3 in

Dipilih s_f = 3 in



Diketahui :

OD = 4,3851 m

ID = 4,366 m

a = ID/2 = 85,9452 in = 2,1830 m

b = ID/4 = 42,97258 in = 1,0915 m

OA = $t_h + s_f + b$

= (0,375 + 3 + 42,97258) in = 46,348 in = 1,1772 m

Tinggi reaktor = Tinggi *shell* + 2*tinggi *head*

= (4,6033) m + (2*1,1772) m = 6,9578 m

= 273,9288 in

= 22,82745 ft

9. Perancangan Coil Pendingin

Kebutuhan air pendingin

Kondisi operasi isothermal

Jumlah panas yang diserap berdasarkan perhitungan neraca panas :

Q = 2.035.542,839 kJ/jam = 1.929.424,492 Btu/jam

$T_{operasi}$ = 40 ^oC = 313,15 K = 104 ^oF

Pendingin :

- Suhu air masuk t_1 = 30 ^oC = 303,15 K = 86 ^oF
- Suhu air keluar t_2 = 35 ^oC = 308,15 K = 95 ^oF

Sifat fisis air pada suhu rata-rata (42,5) :

Cp_{air} = 75,337 Btu/lbm.F = 4,181 kJ/kg.K

Jumlah air yang dibutuhkan :

$$M_{air} = \frac{Q}{Cp.(t_2 - t_1)}$$

$$= \frac{2.035.542,839}{(4,181)(308,15-303,15)}$$

= 97.371,09971 kg/jam

= 27,0475 kg/s

Volume pendingin yang diperlukan :

dengan nilai ρ_{air} pada suhu 30 ^oC = 1.022,8753

$V_{pendingin}$ = 97.371,09971/1022,8753

= 95,1935 m^3/jam

= 0,0264 m^3/s

ΔT *Log Mean Temperature Difference* (ΔT_{LMTD})

$$\Delta T_{LMTD} = \frac{(T - t_1) - (T - t_2)}{Ln\left(\frac{T - t_1}{T - t_2}\right)}$$

$$= \frac{(104-86)-(104-95)}{Ln\left(\frac{104-86}{104-95}\right)}$$

= 12,9843 ^oF

Pipa koil pendingin

Ukuran pipa koil = 1,5-2,5 in (Perry, 1999 hal 11.20)

Dipilih IPS = 2,5 in

Spesifikasi pipa koil : (Kern, 1983 hal 844)

Diameter pipa luar (OD) = 2,88 in = 0,0732 m = 0,2400 ft

Schedule number (SN) = 40

Diameter dalam (ID) = 2,469 in = 0,0627 m = 0,2058

Flow area per pipe (ao) = 4,79 in^2 = 0,003 m^2

Surface area per linier ft (Ao) = 0,753 ft^2/ft = 0,230 m^2/m

Susunan koil = helix

Diameter helix (Dh) = (0,7-0,8)*$ID_{reaktor}$ (Rase, 1977 hal 361)

= 0,75 * 4,366 m = 3,275 m = 10,743 ft

Jarak antar lilitan (l) = (1-1,5)*OD (Perry, 1999)

= 1,5 * 0,0732 = 0,110 m

Koefisien transfer panas dalam koil

Digunakan data air pendingin :

$$\frac{hi.ID}{k} = 0{,}027 \left| \mathrm{Re}^{0,8} . \mathrm{Pr}^{\frac{1}{3}} \right| \left[1 + 3{,}5 \frac{ID}{Dh} \right]$$

(Kern, 1983 hal 103)

dengan :

h_i = Koefisien transfer panas konveksi dalam koil, Btu/jam.ft^2.F

ID = Diameter dalam koil, ft

k = Konduktivitas panas air, Btu/jam.ft.F

D_h = Diameter helix, ft

Re = Bilangan Reynold

Pr = Bilangan Prandtl

Mencari nilai Re

$$Re = \frac{Gt.ID}{\mu_{air}}$$ dengan μ_{air} = 9,00E-04 kg/m.s

Gt = $Gt = \frac{m_{air}}{ao} = \frac{27,0475}{0,003} = 8.752,348 \frac{kg}{m^2.s}$

maka,

$$Re = \frac{Gt.ID}{\mu_{air}}$$

$$= \frac{(8.752,348)(0,0627)}{(9,00E-04)}$$

= 609.869,4748

Mencari nilai Pr

$$Pr = \left[\frac{Cp.\mu}{k}\right]_{air}$$

dengan,

Cp = 1,003 Btu/lbm.°F

k = 0,655 Btu/jam.ft.°F

μ = 2,082 lbm/ft.jam

$$= \left[\frac{(1,003)(2,082)}{(0,655)}\right]_{air}$$

= 3,188

Mencari nilai h_i

$$hi = 0,027.\frac{k}{ID}.Re^{0,8}.Pr^{\frac{1}{3}}.\left[1 + 3,5\frac{ID}{DH}\right]$$

= 5.734,2755 Btu/jam.ft^2.°F

= 7,5318 kcal/s.m^2.°C

Koefisien transfer panas dalam koil dilihat dari luar

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

Rase, 1977 hal. 664

$$= (5.734,2755)\frac{(0,2058)}{(0,2400)}$$

$= 4.915,9466$ Btu/jam.ft^2.^{o}F

$= 6,4570$ kcal/s.m^2.^{o}C

Koefisien konveksi di luar koil

Digunakan data fluida di dalam reaktor

$$ho = 0,06\left(\frac{kc}{OD}\right)\left(\frac{\rho c}{\rho g}\right)^{0,28}\left(\frac{OD.Gg}{\mu c}\right)^{0,87}\left(\frac{Cpc.\mu c}{kc}\right)^{0,4}$$

Dengan :

h_o = koefisien konveksi di luar koil, kcal/m^2.s.^{o}C

k_c = konduktifitas panas cairan, kcal/s.m^2.^{o}C

OD = diameter luar pipa koil, m

ρ_c = densitas cairan, kg/m^3

ρ_g = densitas gas, kg/m^3

G_g = *superficial mass velocity of gas*, kg/m^2.s

μc = viskositas cairan, kg/m.s

Cp_c = panas spesifik cairan, kcal/kg.^{o}C

dan nilai Gg,

$$Gg = \frac{M_{cairan}}{{}^1/_4 . \pi . ID_r^2}$$

$$= \frac{26.716,027}{({}^1/_4)(\pi)(4,366)}$$

$= 1.785,378$ kg/m^2.jam

maka nilai h_o,

$$h_o = 0{,}06\left(\frac{kc}{OD}\right)\left(\frac{\rho c}{\rho g}\right)^{0,28}\left(\frac{OD.Gg}{\mu c}\right)^{0,87}\left(\frac{Cpc.\mu c}{kc}\right)^{0,4}$$

= 4,3390 kcal/s.m^2.^{o}C

= 2.618,3614 Btu/jam.ft^2.^{o}F

Koefisien transfer panas keseluruhan (U_c)

$$U_c = \frac{h_{io}.h_o}{h_{io} + h_o}$$ (Pers. 6.7, Kern, 1950)

$$= \frac{(4.915{,}9466)(2.618{,}3614)}{(4.915{,}9466) + (2.618{,}3614)}$$

= 1.708,4150 Btu/jam.ft^2.^{o}F = 2,2911 kcal/s.m^2.^{o}C

Koefisien transfer panas keseluruhan saat kotor (U_d)

Dengan, Rd = *dirt factor/fouling factor* = 0,005 (Tabel 12, Kern, 1950)

$$\frac{1}{U_D} = \frac{1}{U_c} + Rd$$

$$U_D = \frac{1}{\frac{1}{U_c} + Rd}$$

U_D = 179,0402 Btu/jam.ft^2.^{o}F

U_D air-zat organik adalah 100-200 Btu/jam.ft^2.^{o}F, sehingga U_d memenuhi syarat.

Luas kontak perpindahan panas

$$At = \frac{Q}{U_d.\Delta T_{LMTD}}$$

= 829,9685 ft^2

= 77,1057 m^2

Panjang koil

$$L_c = \frac{A_t}{a_o}$$, Lc = 205,6701 m

dimana,

b = 0,500*AD (diameter helix = ID_h)

x = AB (jarak antar lilitan)

a = $(b^2 + x^2/4)^{0,5}$

BD^2 = $AD^2 + AB^2$

a = $(b^2 + x^2/4)^{0,5}$

Keliling koil (Kl_c) = $2.\pi.((a^2 + b^2)/2)^{0,5}$

= $2.\pi.((b^2 + x^2/4 + b^2)/2)^{0,5}$

= $2.\pi.(b^2 + x^2/8)^{0,5}$

b = 1,6373

a = 0,055

$(b^2 + x^2/8)^{0,5}$ = 1,6373

x = 0,110

Keliling koil (Kl_c) = 10,2849 m

Jumlah koil (N_t)

$$N_t = \frac{Lc}{Kell.\ koil}$$

$$= \frac{(205,6701)}{10,2849}$$

$$= 19,9973$$

Untuk perancangan dipilih jumlah koil (N_t) = 20 lilitan

Koreksi nilai :

$Lc_{koreksi}$ = Kl_c x N_t

= (10,2849 x 20) m = 205,6974 m

$At_{koreksi}$ = L_c x a_o

= (205,6974 x 0,230) = 47,2082 m^2 = 508,1492 ft^2

$Ud_{koreksi} = \dfrac{Q}{A_t . \Delta T_{LMTD}}$

= 292,4284 Btu/jam.ft^2.^{o}F

Tinggi koil (H_c) dan Volume koil (V_c)

- Tinggi koil (H_c)

$$H_c = (N_t - 1) \text{ x jarak lilitan} + (N_t * OD_{koil})$$

= ((20 – 1) x 0,110) + (20 x 0,0732)

= 3,5479 m

- Volume koil (V_c)

$$V_c = {}^1/_4 . \pi . (OD_{koil})^2 * L_c$$

= 0,8641 m^3

10. Perancangan Pipa

D_i optimum = 3,9 x $Q^{0.43}$ x $\rho^{0.13}$ (Pers. 6.32, Wallas, 1988)

dengan, Di = diameter pipa optimum, in

Q = debit, ft^3/s

ρ = densitas, lbm/ft^3

Ukuran pipa pemasukan umpan dari tangki pencampur

Debit cairan = 20,2655 m^3/jam = 0,1988 ft^3/s

ρ_{cairan} = 1,3183 gr/ml = 82,2988 lbm/ft^3

D_i, opt = 3,4545 in

Dari tabel 11, Kern, 1950 dipilih pipa dengan spesifikasi :

ID = 4,026 in

OD = 4,5 in

IPS = 4 in

ao = 12,7 in^2

SN = 40

Ukuran pipa pemasukan umpan gas (CO_2)

Debit cairan = 382,2643 m^3/jam = 3,7499 ft^3/s

ρ_{gas} = 0,0069 gr/ml = 0,4333 lbm/ft^3

D_i, opt = 6,1756 in

Dari tabel 11, Kern, 1950 dipilih pipa dengan spesifikasi :

ID = 7,625 in

OD = 8,625 in

IPS = 8 in

ao = 45,7 in^2

SN = 80

Ukuran pipa pengeluaran produk

Debit cairan = 34,0268 m^3/jam = 0,3338 ft^3/s

ρ_{cairan} = 0,8429 gr/ml = 52,6234 lbm/ft^3

D_i, opt = 4,0230 in

Dari tabel 11, Kern, 1950 dipilih pipa dengan spesifikasi :

ID = 4,026 in

OD = 4,5 in

IPS = 4 in

ao = 12,7 in^2

SN = 40

Ukuran pipa pengeluaran gas (CO_2)

Debit cairan = 72,8914 m^3/jam = 0,7150 ft^3/s

ρ_{gas} = 0,0069 gr/ml = 0,4333 lbm/ft^3

D_i, opt = 3,0284

Dari tabel 11, Kern, 1950 dipilih pipa dengan spesifikasi :

ID = 3,068 in

OD = 3,5 in

IPS = 3 in

ao = 7,38 in^2

SN = 40