

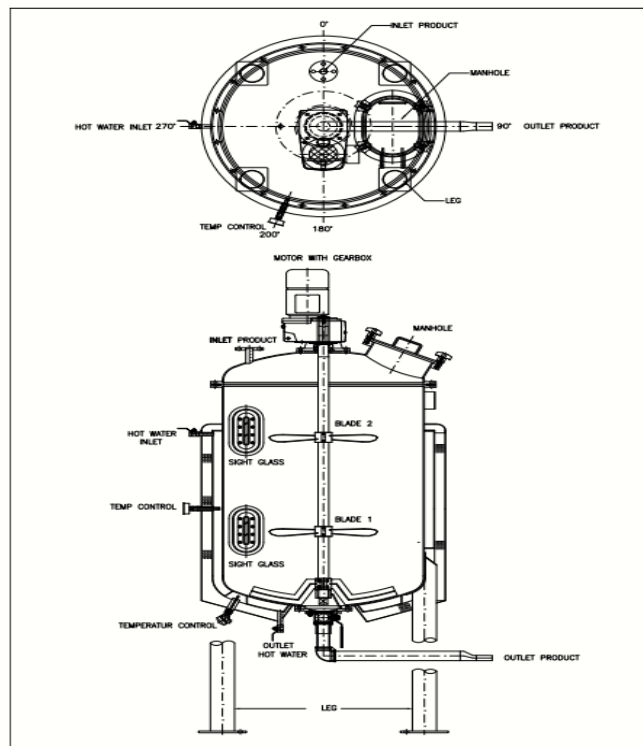
# LAMPIRAN

## Desain Proses Slaker-01

Fungsi : Tempat melarutkan kapur mentah (quicklime) dan H<sub>2</sub>O sehingga terbentuk larutan Ca(OH)<sub>2</sub>

Type : Continuous quicklime slaker

Gambar :



Sumber : Bapak Rumadi

Data-data :

Temperatur = 75 °C

Tekanan = 2 atm = 29,4 psia

Densitas campuran =  $1017,5123 \text{ kg/m}^3 = 63,4928 \text{ lb/ft}^3$

Laju alir massa =  $9243,8409 \text{ kg/jam}$

Waktu tinggal =  $40 \text{ menit} = 0,67 \text{ jam}$

(Peters and Timmerhaus, 1991:37)

Over design =  $20\%$

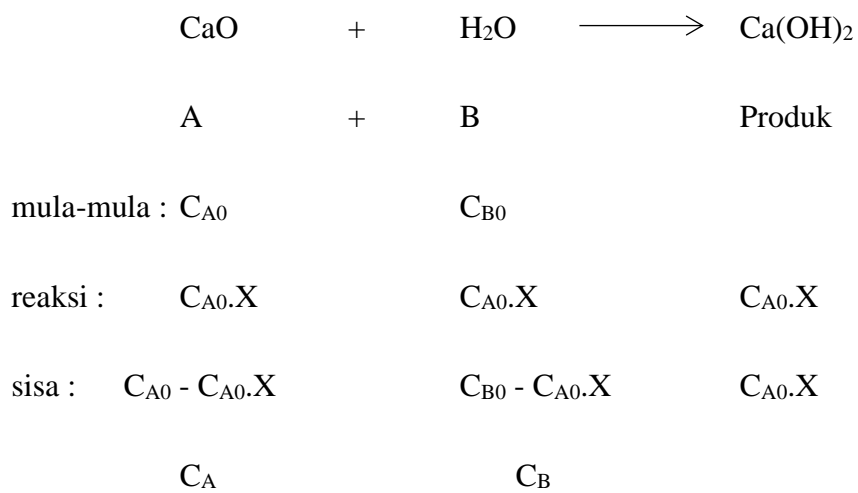
Konversi =  $0,97$

Perhitungan :

A. Kinetika reaksi

1. Menentukan persamaan laju reaksi :

Reaksi :



2. Densitas Komponen

$\rho_{\text{campuran}} = 1/\sum w_i/\rho_i = 1017,5123 \text{ kg/m}^3$

$\rho_{\text{solid}} = 1/\sum w_i/\rho_i = 57572,7043 \text{ kg/m}^3$

$$\rho_{\text{fluida}} = 1/\sum w_i/\rho_i = 1035,8189 \text{ kg/m}^3$$

### 3. Menentukan $C_{A0}$ dan $C_{B0}$

$$C_{A0} = \text{mol A}/F_v = 2,7166 \text{ kmol/m}^3$$

$$C_{B0} = \text{mol B}/F_v = 51,7767 \text{ kmol/m}^3$$

$$C_A = C_{A0} (1-X_A) = 0,0815 \text{ kmol/m}^3$$

$$C_B = C_{B0} - C_{A0} \cdot X_A = 49,1417 \text{ kmol/m}^3$$

$$M = C_{B0}/C_{A0} = 19,0596$$

NM total :

$$\text{in} \quad - \quad \text{out} \quad - \quad \text{rx} \quad = \quad 0$$

$$F_{A0} \quad - \quad F_A \quad - \quad (-r_A) \cdot V \quad = \quad 0$$

$$F_{A0} - (F_{A0} - F_{A0} \cdot X) = (-r_A) \cdot V$$

$$F_{A0} - F_{A0} + F_{A0} \cdot X = (-r_A) \cdot V$$

$$F_{A0} \cdot X = (-r_A) \cdot V$$

$$F_v \cdot C_{A0} \cdot X/V = (-r_A)$$

$$F_v \cdot C_{A0} \cdot X/(-r_A) = V$$

Dimana :  $(-r_A) = k_1 \cdot C_A \cdot C_B$

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

$$C_B = C_{B0} - C_{A0} \cdot X$$

$$C_B = C_{A0}(C_{B0}/C_{A0} - X)$$

$$C_B = C_{A0}(M-X)$$

Maka :

$$\begin{aligned} V &= Fv.C_{A0}.X / k_1.C_A.C_B \\ &= Fv.C_{A0}.X / k_1.C_{A0}(1-X).C_{A0}(M-X) \\ &= Fv.X / k_1.C_{A0}(1-X)(M-X) \end{aligned}$$

Jadi :

$$k = Fv.X / V.C_{A0}(1-X)(M-X)$$

Dimana :  $V = \tau . Fv$

$$k = Fv.X / \tau . Fv.C_{A0}(1-X)(M-X)$$

#### 4. Menentukan Konstanta kecepatan reaksi

$$k = Fv.X / \tau . Fv.C_{A0}(1-X)(M-X)$$

$$k = 0,9869 \text{ m}^3/\text{kmol.jam}$$

maka :

$$\begin{aligned} (-r_A) &= k.C_A.C_B \\ &= 4,0 \text{ kmol/m}^3.\text{jam} = 0,0040 \text{ kmol/L.jam} \end{aligned}$$

Menentukan Volume Reaktor

$$\begin{aligned} V &= Fv.X / k_1.C_{A0}(1-X)(M-X) \\ &= 5,6428 \text{ m}^3/\text{jam} \end{aligned}$$

Neraca massa total :

$$F_{A \text{ in}} - F_{A \text{ out}} + (-r_A).V = 0$$

$$22,9934 - F_{A \text{ out}} + 22,3036 = 0$$

$$F_{A \text{ out}} = 0,6898 \text{ kmol/jam}$$

## B. Dimensi Reaktor

### 1. Menentukan Dimensi Reaktor

Untuk operasi dengan tekanan dalam rentang 1 atm (15 psig) sampai 14 atm (200 psig), menggunakan : Torispherical Flanged and Dished Head (Brownell n Young, 1959: hal 92).

#### a. Diameter dan tinggi reaktor

$$\text{- Diketahui } V = 5,6428 \text{ m}^3 = 199,2505 \text{ ft}^3$$

(Over design : 20%)

$$\text{- } V_{\text{cairan}} = 6,7713 \text{ m}^3 = 239,1006 \text{ ft}^3$$

Pengambilan H/D diusahakan mendekati 1, karena jika H/D terlalu besar atau terlalu kecil maka :

> Pengadukan tidak sempurna

> Distribusi panas tidak merata

Dipilih :

$$H/D = 2 \text{ (Brownell,1959)}$$

$$H = 2D$$

$$\text{Volume shell} = \frac{\pi}{4} 2D^3$$

$$6,7713 = \frac{\pi}{2} D^3$$

$$D = \sqrt[3]{\frac{2 \times V_{shell}}{\pi}}$$

$$D = 1,6278 \text{ m}$$

$$= 64,0852 \text{ in}$$

Jumlah reaktor yang digunakan : 1 RATB

Dengan :

$$V_{shell} = 6,7713 \text{ m}^3$$

$$D_{shell} = 1,6278 \text{ m} = 64,0852 \text{ in} = 5,3404 \text{ ft}$$

$$H_{shell} = 3,2555 \text{ m} = 128,1705 \text{ in} = 10,6809 \text{ ft}$$

Dipilih standart ;

$$D_{shell} = 1,6 \text{ m} = 64,1 \text{ in} = 5,3 \text{ ft}$$

$$H_{shell} = 3,3 \text{ m} = 128,2 \text{ in} = 10,7 \text{ ft}$$

## 2. Menentukan Tinggi Cairan

$$HL = V_{shell} / (\pi D^2 / 4)$$

$$HL = 3,2555 \text{ m} = 128,1705 \text{ in} = 10,6809 \text{ ft}$$

### 3. Menentukan Tekanan Desain

Tekanan operasi (Pops) = 2 atm (29,4 psia)

Keterangan :

g = Percepatan gravitasi = 32,174 ft/det<sup>2</sup>

gc = Faktor konversi percepatan gravitasi = 32,174 g.cm/gf.det<sup>2</sup>

$$P_{\text{hidrostatik}} = \frac{\rho_{\text{mix}} \left( \frac{g}{g_c} \right) H_L}{144}$$

$$= 4,7094 \text{ psia}$$

P abs = P operasi + P hidrostatik

$$= 29,4 + 4,7094$$

$$= 34,1012 \text{ psia}$$

Tekanan desain 5-10% diatas tekanan kerja *absolute* (Coulson, 1988:637) Tekanan desain yang dipilih 10% diatasnya

P desain = 1,1 x P abs

$$= 37,5114 \text{ psia} = 22,8114 \text{ psig}$$

### 4. Menentukan Ketebalan dinding reaktor

Tipe material penyusun reaktor adalah *Carbon Steel SA-216*. Hal ini disebabkan:

> Mempunyai allowable stress yang besar

- > Struktur kuat
- > Harga yang relatif lebih murah
- > Dapat menangani  $\text{Ca(OH)}_2$

(pers 14.34 Brownell, 1959:275)

Ketebalan dinding shell :

$$t_s = \frac{P \cdot r_i}{f \cdot E - 0,6P} + C$$

Keterangan :

$t_s$  = tebal shell, in

$r_i$  = jari-jari shell =  $D/2 = 0,8139 \text{ m} = 32,0426 \text{ in} = 2,6702 \text{ ft}$

$f$  = allowable stress untuk Carbon Steels SA 299

= 18750 psi (Table 13.1 Brownell, 1959:251)

$E$  = Joint efisiensi tipe double-butt weld = 80% = 0,8 (Table 13.2

Brownell, 1959:254)

$C$  = Corrosian allowance = 0,0125 in/yr = 0,125 in/10 yr (Table 6.

Timmerhaus, 1991:542)

$P$  = Tekanan desain = 22,8114 psig

Maka :

$t_s = 0,1738 \text{ in}$

Diambil : (Table 5.4 Brownel & young, 1959:87)

$t_s$  standart = 1/4 in = 0,25 in



## 5. Menentukan Diameter luar tangki

Standarisasi OD :

$$OD = ID + 2.ts$$

$$= 64,5852 \text{ in}$$

Diambil OD standart = 66 in (*Table 5.7 Brownell & young, 1959:91*)

## 6. Perancangan Head Tangki

Bentuk : *Torispherical dished head*

Digunakan untuk tangki dengan tekanan dalam rentang 15 psig

(1,020689 atm) - 200 psig (13,60919 atm)

Menentukan dimensi tutup atas dan bawah :

Ketebalan *torispherical head* (*Pers. 7.77 Brownell & Young, 1959*)

$$th = \frac{P \cdot r_c \cdot W}{2 \cdot f \cdot E - 0,2 \cdot P} + C$$

Keterangan :

th = Tebal head, in

W = Faktor intensifikasi stress

f = *allowable stress* untuk *Carbon Steels SA 299* = 18750 psi (*Table 13.1 Brownell, 1959:251*)

E = *Joint efisiensi tipe double-butt weld* = 80% = 0,8 (*Table 13.2 Brownell, 1959:254*)

$C = \text{Corrosion allowance} = 0,0125 \text{ in/yr} = 0,125 \text{ in/10 yr}$  (Table 6.

*Timmerhaus, 1991:542)*

$P = \text{Tekanan desain} = 22,8114 \text{ psig}$

Untuk  $OD = 66 \text{ in}$  (Table 5.7 Brownell & young, 1959:91)

*inside corner radius (icr) = 4 in*

*crown radius (rc) = 66 in*

Dengan, 
$$W = \frac{1}{4} \left( 3 + \sqrt{\frac{rC}{icr}} \right)$$

$W = 1,7655 \text{ in}$

Jadi :

$th = 0,21 \text{ in}$

Digunakan tebal head standard = 1/4 in

Tebal bottom = tebal head = 0,25 in

Untuk  $th = 1/4 \text{ in}$ , maka  $sf = 1,5 - 2,5 \text{ in}$  (Tabel 5.6 Brownell, 1959:88)

Dipilih,  $sf = 2 \text{ in}$

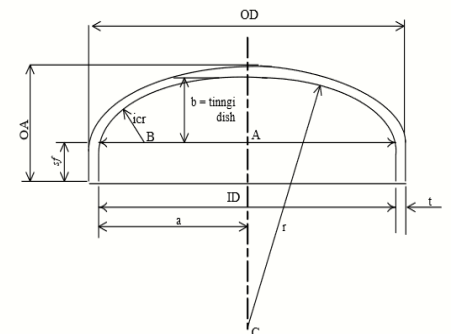
$$AB = (ID/2) - icr$$

$$= 28,0426 \text{ in}$$

$$BC = rc - icr$$

$$= 62,000 \text{ in}$$

$$r_c - \sqrt{BC^2 - AB^2}$$



Gambar C.13. Torispherical Dished head Activate Windows

Depth of Dish (b) =

$$= 10,7043 \text{ in}$$

Tinggi Head (OA) =  $t_h + b + sf$  (*Brownell and Young, 1959:87*)

$$= 12,9543 \text{ in}$$

Jadi :

Tinggi *dished head* (Hd) = OA

$$= 12,9543 \text{ in} = 1,0795 \text{ ft} = 0,2521 \text{ m}$$

Tinggi cairan di shell (HL,S) = HL - OA

$$= 115,2161 \text{ in} = 9,6013 \text{ ft} = 2,9265 \text{ m}$$

Tinggi total reaktor = Hs + 2. Hd

$$= 154,0791 \text{ in} = 12,8399 \text{ ft} = 3,9136 \text{ m}$$

Volume pada sf (Vsf) =  $(\pi/4) \cdot D^2 \cdot sf$

$$= 6447,8593 \text{ in}^3 = 3,7314 \text{ ft}^3 = 0,1056 \text{ m}^3$$

Volume *head torispherical* (Vd) =  $0,000049 \text{ ID}^3$  (*pers. 5.11.*

*Brownell, 1959:88*)

$$Vd = 12,8964 \text{ in}^3 = 0,0075 \text{ ft}^3 = 0,0002 \text{ m}^3$$

Volume sebuah head =  $2(Vd + Vsf)$

$$= 12921,51153 \text{ in}^3 = 7,4777 \text{ ft}^3 = 0,2116 \text{ m}^3$$

Vreaktor =  $V_{shell} + V_{head}$

$$V_{reaktor} = 6,9829 \text{ m}^3 = 1844,7004 \text{ gallon}$$

## C. Desain Sistem Pengaduk

### 1. Dimensi Pengaduk

Digunakan jenis *six pitched blade turbine*. Karena dapat digunakan untuk campuran berviskositas  $< 10.000$  cp (*Geankoplis, 1993:143*) dan cocok untuk pengadukan suspensi solid (*Wallas, 1990:298*). Berikut ini dijabarkan geometrinya:

$$D_t/D_i = 3 \quad (\text{Brown, 1950:507})$$

$$Z_i/D_i = 1 \quad (\text{Brown, 1950:507})$$

$$w/D_i = 0,17 \quad (\text{Brown, 1950:507})$$

$$r = 0,25 D_i \quad (\text{Metcalf and Eddy, 1991})$$

$$\text{Offset 1} = 0,5 D_i \quad (\text{Wallas, 1990:288})$$

$$\text{Offset 2} = 0,17 w \quad (\text{Wallas, 1990:288})$$

$$D_d = 0,67 D_i \quad (\text{Geankoplis, 1993:144})$$

$$W/D_i = 0,2 \quad (\text{Geankoplis, 1993:144})$$

Keterangan :

$D_i$  = Diameter *impeller*, m

$D_t$  = Diameter tangki, m

$Z_i$  = Tinggi *impler* dari dasar tangki, m

$w$  = Lebar *baffle*, m

W = Tebal baffle, m

Dd = Diameter batang penyangga impeller, m

r = impeller blade length, m

Offset 1 = Jarak baffle dari dasar tangki, m

Offset 2 = Jarak baffle dari permukaan cairan, m

Dimensi pengaduk adalah :

$D_i = (1/3) \times D_t = 0,5426 \text{ m}$

$Z_i = 1 \times D_i = 0,5426 \text{ m}$

$w = 0,17 \times D_i = 0,1989 \text{ m}$

$r = 0,25 \times D_i = 0,1356 \text{ m}$

Offset 1 =  $0,5 \times D_i = 0,5850 \text{ m}$

Offset 2 =  $0,17 \times w = 0,0338 \text{ m}$

$D_d = 0,67 \times D_i = 0,3635 \text{ m}$

$W = 0,2 \times D_i = 0,1085 \text{ m}$

Jumlah *baffle* = 4

Panjang *baffle* =  $H_{L,S} - (\text{Offset 1} + \text{Offset 2})$   
= 2,31 m

## 2. Kecepatan Putaran Pengaduk

a. Menentukan jumlah pengaduk

$$\text{Jumlah pengaduk} = \text{WELH}/\text{ID}$$

Keterangan :

$$\text{WELH} = \text{water equivalent liquid height} = \text{HL},S \times \text{sg}$$

ID = Diameter dalam reaktor , in

sg = *specific height*

$$\text{sg} = \rho_{\text{campuran}}/\rho_{\text{air}} = 1,0175$$

Maka :

$$\text{WELH} = 117,2338 \text{ in}$$

Sehingga:

Jumlah impeller = 2 buah

$$N = \frac{600}{\pi * \text{Di}(\text{ft})} \sqrt{\frac{\text{WELH}}{2 * \text{Di}(\text{in})}}$$

Kecepatan putaran pengaduk :

Keterangan :

N = Kecepatan putaran pengaduk

$$\text{Di} = \text{Diameter impeller} = 0,5426 \text{ m} = 21,3617 \text{ in} = 1,7801 \text{ ft}$$

$$\text{WELH} = \text{Water equivalent liquid height} = 117,2338 \text{ in}$$

Maka :

$$N = 177,8113 \text{ rpm} = 2,9635 \text{ rps (Table 9.2 Mc. Cabe 1993:252)}$$

### 3. Daya pengaduk

(pers 9-24 Mc.Cabe,1993)

Keterangan :

$K_T$  = konstanta untuk *impeller* = 1,63 (Table 9.2 Mc. Cabe  
1993:252)

$D_i$  = Diameter *impeller* = 0,5426 m = 1,780 ft

$g_c$  = percepatan gravitasi = 32,174 ft/s<sup>2</sup>

$N$  = kecepatan putaran = 2,9635 rps

$\rho$  = densitas campuran = 63,4928 lb/ft<sup>3</sup>

Maka :

$P = 2,7211$  HP

$$P = \frac{K_T \cdot \rho \cdot N^3 \cdot D_i^5}{g_c}$$

Daya yang hilang (*Gland loss*)

Hilang (*gland loss*) = 10% x Daya Pengaduk (MV. Joshi)

$$= 0,2721 \text{ HP}$$

Daya Input

Daya Input = Kebutuhan daya pengaduk + Hilang (*gland loss*)

$$= 2,7211 + 0,2721$$

$$= 2,9932 \text{ HP}$$

Efisiensi motor ( $\eta$ )

$$(\eta) = 80 \%$$

Daya motor yang digunakan:

$$P = 100/80 \times 0,6323 \text{ HP}$$

$$= 4 \text{ HP}$$

Diambil, standart daya motor yang digunakan ( $P$ ) = 5 HP (*Standard NEMA, Resa and Barrow, p.358*)

Panjang batang sumbu pengaduk (*Axis lenght*)

Axis lenght ( $L$ ) = tinggi total reaktor + jarak dari motor ke bagian bearing  
- jarak pengaduk dari dasar tangki

$$L = 3,6758 \text{ m}$$

$$\text{Diameter sumbu} = \frac{Z_p \times 16}{\pi}$$

Keterangan :

$$Z_p = T_m / f_s$$

$T_m$  = Torsi maksimum

$Z_p$  = *Shear stress*

$f_s$  = *Section of shaft cross section*



Material sumbu yang digunakan adalah *commercial cold rolled steel*

Axis shear stress yang diizinkan,  $f_s = 550 \text{ kg/cm}^2$

Batasan elastis pada tegangan =  $2460 \text{ kg/cm}^2$

\*Menghitung  $T_m$

$$T_m = (1,5 \text{ atau } 2,5) \times T_c \quad (\text{Dari } M.V \text{ Joshi, pers } 14.10, \text{ hal } 400)$$

Diambil :

$$T_m = 1,5 \cdot T_c$$

$$T_c = (P \cdot 75 \cdot 60)/(2\pi N) = 20,1495 \text{ kg, m}$$

$$T_m = 30,2242 \text{ kg, m}$$

\*Menghitung  $Z_p$

$$Z_p = T_m/f_s$$

$$= 5,4953 \text{ cm}$$

\*Menghitung diameter sumbu ( $d$ )

$$d^3 = 28,0016 \text{ cm}$$

$$d = 3,0366 \text{ cm} = 0,0304 \text{ m}$$

#### D. Neraca Panas Slaker-01

Kondisi operasi :

$$T = 75 \text{ }^\circ\text{C} = 348,15 \text{ K}$$

$$T_{\text{ref}} = 25 \text{ }^\circ\text{C} = 298,15 \text{ K}$$

Panas masuk dari Heater-01 ( $Q_2$ ) :

$$Q_2 = 2307647,4699 \text{ kJ}$$

a. Panas sensibel yang dibawa H<sub>2</sub>O masuk (Q<sub>2</sub>)

Komponen	kg	n (kmol)	ΔH (kJ/kmol)	Q <sub>2</sub> (kJ)
H <sub>2</sub> O	7888,4390	438,2466	5265,6368	2307647,4699
Total	7888,43898			2307647,4699

b. Panas yang dibawa feed masuk (Q<sub>3</sub>)

Komponen	kg	n (kmol)	ΔH (kJ/kmol)	Q <sub>3</sub> (kJ)
CaO	1287,6318	22,9934	28,8885	664,2455
SiO	27,1080	0,4518	1435,1338	648,3944
MgO	16,2648	0,4066	1200,4410	488,1240
Fe <sub>2</sub> O <sub>3</sub>	2,8463	0,0178	51,9989	0,9250
Al <sub>2</sub> O <sub>3</sub>	6,0993	0,0598	-4844,8460	-289,7079
S	0,0949	0,0030	-234,8378	-0,6963
P	0,0407	0,0013	1136,6434	1,4909
Moisture	15,3160	0,8509	3760,6226	3199,8806
Total	1355,401887			4712,6562

c. Panas Reaksi

Reaksi :

>> Panas reaksi pembentukan standar (ΔH<sub>f</sub>)

1. Entalpi pembentukan standar pada reaktan

Komponen	kmol	ΔH <sub>f</sub> (kJ/kmol)	Q (kJ)
CaO	22,9934	-635,09	-14602,8942
H <sub>2</sub> O	438,2466	-285,83	-125264,0285
Total			-139866,9227

2. Entalpi pembentukan standar pada produk

Komponen	kmol	ΔH <sub>f</sub> (kJ/kmol)	Q (kJ)
Ca(OH) <sub>2</sub>	22,3036	-868,07	-19361,1053
Total			-19361,1053

Jadi :  $Q = Q_{\text{produk}} - Q_{\text{reaktan}}$

$$Q = -2307834,4178 \text{ kJ}$$

Maka, Panas reaksi yang dihasilkan :

$$Q_{rx} = \Delta H_{R,298} + \Delta Q_{rx}$$

$$Q_{rx} = -2187328,6003 \text{ kJ (Reaksi eksotermis)}$$

d. Panas sensibel yang dibawa produk keluar ( $Q_4$ )

Komponen	kg	kmol	$\Delta H$ (kJ/kmol)	$Q_4$ (kJ)
CaO	38,6290	0,6898	28,8885	19,9274
SiO	27,1080	0,4518	1435,1338	648,3944
MgO	16,2648	0,4066	1200,4410	488,1240
Fe <sub>2</sub> O <sub>3</sub>	2,8463	0,0178	51,9989	0,9250
Al <sub>2</sub> O <sub>3</sub>	6,0993	0,0598	-4844,8460	-289,7079
S	0,0949	0,0030	-234,8378012	-0,6963
P	0,0407	0,0013	1136,643411	1,4909
H <sub>2</sub> O	7502,2898	416,7939	5265,6368	2194685,1808
Ca(OH) <sub>2</sub>	1650,4680	22,3036	21,4	477,2975
Total	9243,840867			2196030,9357

e. Panas yang dibutuhkan air pendingin pada jaket pendingin slaker-01  
Jumlah pendingin yang dibutuhkan :

Panas Input (kJ)		Panas Output (kJ)	
Q <sub>2</sub> =	2307647,4699	Q <sub>4</sub> =	2196030,9357
Q <sub>3</sub> =	4712,6562	Q <sub>rx</sub> =	-2187328,6003
Q Sub Total =	2312360,126	Sub Total =	8702,33537
Beban Pendingin (Q <sub>c</sub> ) =	0,0000	Q <sub>c</sub> =	2303657,7907
Total =	2312360,1260	Total =	2312360,1260
Selisih			0,0000

$$Q_c = 2303657,791 \text{ kJ}$$

Pendingin yang digunakan adalah air :

$$T_{in} = 30 \text{ }^\circ\text{C} = 303,15 \text{ K}$$

$$T_{out} = 60 \text{ }^\circ\text{C} = 333,15 \text{ K}$$

$$T_{ref} = 25 \text{ }^{\circ}\text{C} = 298,15 \text{ K}$$

$$c_p \text{ H}_2\text{O} = 4,1801 \text{ kJ/kg.K}$$

Massa air pendingin yang dibutuhkan :

$$Q_c = m \cdot C_p \cdot \Delta T$$

$$m = Q_c / C_p \cdot \Delta T$$

$$= 18370,0373 \text{ kg/jam}$$

Panas yang dibawa air (H<sub>2</sub>O) masuk :

$$Q_{c \text{ in}} = m \cdot C_p \cdot \Delta T$$

$$= 383942,9651 \text{ kJ}$$

Panas yang dibawa air (H<sub>2</sub>O) keluar :

$$Q_{c \text{ out}} = m \cdot C_p \cdot \Delta T$$

$$= 2687600,7558 \text{ kJ}$$

#### E. Desain kebutuhan pendingin

Reaksi yang berlangsung dalam reaktor bersifat eksotermis, sehingga panas yang dilepaskan harus diserap agar tidak menyebabkan kenaikan suhu. Jaket/koil yang dialiri air pendingin digunakan untuk menjaga temperatur reaktor agar suhu konstan pada 75°C.

Perbedaan temperatur logaritmik rata-rata adalah :

Fluida Panas	Temperatur (°F)	Fluida Dingin	Selisih
167	Temp. Tinggi	140	27
167	Temp. Rendah	86	81
0		54	

$$\Delta T_{LMTD} = \frac{(T_2 - t_1) - (T_1 - t_2)}{\ln \left( \frac{(T_2 - t_1)}{(T_1 - t_2)} \right)}$$

$$= 49,1529 \text{ } ^\circ\text{F}$$

### 1. Perhitungan Jaket Pendingin

Luas perpindahan panas yang tersedia

A = luas selimut reaktor + luas penampang bawah reaktor

$$A = \pi \cdot D_o \cdot H_{L,S} + (\pi/4 \cdot D_o^2)$$

Diketahui :

$$D_o = 66 \text{ in} = 5,5000 \text{ ft}$$

$$H_{L,S} = 9,6013 \text{ ft}$$

Sehingga :

$$A = \pi \cdot D_o \cdot H_{L,S} + (\pi/4 \cdot D_o^2)$$

$$= 189,5614 \text{ ft}^2$$

Luas perpindahan panas yang dibutuhkan Dari tabel.8 (*Kern, Process Heat Transfer ; hal 840*) didapat *Overall heat transfer* UD dengan, hot fluid adalah *aqueous solution* (larut dalam air) dan *cold fluid* adalah *water* dengan UD = 250 - 500 Btu/jam.ft<sup>2</sup>.°F

Dipilih asumsi :

$$UD = 250 \text{ Btu/jam.ft}^2 \cdot ^\circ\text{F}$$

Diketahui :

$$Q = 2303657,7907 = \text{kJ/jam} = 2183446,0162 = \text{Btu/jam}$$

$$\Delta\text{TLMTD} = 49,1529 \text{ } ^\circ\text{F}$$

maka :

$$\begin{aligned} \text{Akebutuhan} &= Q/UD \times \Delta\text{TLMTD} \\ &= 177,6860 \text{ ft}^2 \end{aligned}$$

$$\text{Akebutuhan} < \text{Atersedia} = 177,686 \text{ ft}^2 < 189,5614 \text{ ft}^2$$

sehingga jaket pendingin dapat digunakan.

#### F. Desain Jaket Pendingin

Reaksi yang berlangsung dalam reaktor bersifat eksotermis, sehingga panas yang dilepaskan harus diserap dari reaktor agar tidak menyebabkan kenaikan suhu. Jaket/koil yang dialiri air pendingin digunakan untuk menjaga temperatur reaktor agar suhu konstan pada 75°C.

Diketahui :

$$Q \text{ yang diserap} = 2303657,7907 \text{ kJ/jam} = 2183446,016 \text{ Btu/jam}$$

$$\rho \text{ air pendingin} = 995,7000 \text{ kg/m}^3 = 62,1317 \text{ lb/ft}^3$$

$$m \text{ air pendingin} = 18370,0373 \text{ kg/jam}$$

rate air pendingin = 18,4494 m<sup>3</sup>/jam = 0,0051 m<sup>3</sup>/s

Diambil :

spasi jaket = 2 in

$$\begin{aligned}\text{Diameter dalam jaket (D1)} &= \text{Diameter dalam} + (2 \times \text{tebal dinding}) + (2 \times \text{jarak} \\ &\quad \text{jaket}) \\ &= \text{OD} + (2 \times \text{jarak jaket}) \\ &= 70 \text{ in}\end{aligned}$$

#### 1. Tebal dinding jaket

Bahan : *carbon stell*

$$\begin{aligned}\text{Tinggi jaket (H jaket)} &= H_{L,s} \\ &= 115,2161 \text{ in} \\ &= 9,6 \text{ ft}\end{aligned}$$

P hidrostatik = 49,2808 Psia

$$\begin{aligned}\text{P desain} &= \text{P desain reaktor} + \text{Phidrostatik} \\ &= 86,7922 \text{ Psia} \\ &= 72,0922 \text{ Psig}\end{aligned}$$

Keterangan :

tj = Tebal jaket, in

f = Allowable stress untuk Carbon Steel SA 299 = 18750 psi (Table 13.1  
Brownell, 1959:251)

$E = \text{Joint efisiensi tipe double-butt weld} = 80\%$  (Table 13.2 Brownell, 1959:254)

$C = \text{Corrosion allowance} = 0,0125 \text{ in/yr} = 0,125 \text{ in/10 yr}$

$P = \text{Tekanan desain} = 72,0922 \text{ psig}$

$D = \text{Diameter dalam jaket} = 70 \text{ in}$

Maka :

$t_j = 0,2937 \text{ in}$

Diambil :

$t_j \text{ standart} = 0,3125 \text{ in}$

$\text{Diameter jaket luar } (D_2) = D_1 + (2 \times t_j)$

$$= 70,6250 \text{ in} = 1,7939 \text{ m}$$

$\text{Luas yang dilalui air pendingin } (A) = (3,14/4) \times (D_2^2 - D_1^2)$

$$= 68,9941 \text{ in}^2$$

$$= 0,0445 \text{ m}^2$$

$\text{Kecepatan alir pendingin } (v) = Q_w/A$

$$v = 414,5812 \text{ m/jam}$$

$$= 0,1152 \text{ m/s}$$

2. Tinggi jaket ( $H_j$ )

$\text{Luas perpindahan panas} = (3,14 \times D_t \times H_j) + (0,25 \times 3,14 \times D_t^2)$



$$189,5614 = 6,7690 H_j + 22,3884$$

$$167,1730 = 16,7690 H_j$$

$$H_j = 9,9692 \text{ ft}$$

$$= 3,0386 \text{ m}$$

3. Volume jaket =  $\pi/4 \cdot D^2 \cdot H_j$

$$= 7,6759 \text{ m}^3$$

$$= 271,0717 \text{ ft}^3$$

4. Menentukan kecepatan volumetrik steam :

$$Q_v = W_t / \rho_{air}$$

Dimana :

$$Q_v = \text{kecepatan volumetrik air (m}^3/\text{jam)}$$

$$W_t = \text{kebutuhan steam (kg/jam)}$$

$$\rho_{air} = \text{Densitas air (kg/m}^3\text{)}$$

$$\text{Sehingga, } Q_v = 18,4494 \text{ m}^3/\text{jam}$$

#### G. Penentuan *Manhole*

(*Brownell and young, Ap. F item 4*) dengan *spesifikasi* : Setiap *vessel* yang dalam operasinya melibatkan cairan ataupun yang di dalam nya terdapat alat lain seperti *impeller*, sebaiknya dilengkapi dengan *manhole*. *Manhole* sangat dibutuhkan dalam *vessel* tertutup untuk pemeriksaan, pembersihan kolom dan

perbaikan. Direncanakan *manhole* di pasang pada kolom bagian atas reaktor dengan ukuran standard 20 in berdasarkan *Rekomendasi API standard 12 C*.

Tebal *shell* = 0,3125 in

Tebal *flange* = 1,5 in

Jumlah = 1

Ukuran potongan :

*Weld A* = 0,8750 in

*Weld B* = 1,5 in

Panjang sisi = 42,5 in

Lebar *reinforcement* (W) = 49,0 in

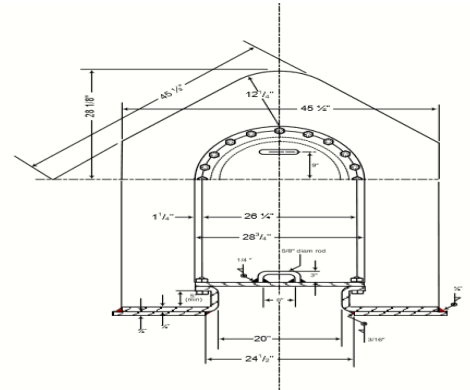
Diameter *manhole* (ID) = 20,0 in

Maksimum diameter lubang (*Dp*) = 27,0 in

Diameter plat penutup :

*Cover plate* = 28,75 in

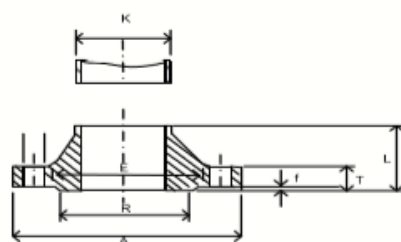
Diameter *bolt circle* (DB) = 25,25 in Manhole



Gambar F.11. *Manhole*

#### H. Perancangan *Nozzle*

Dipilih jenis pipa : *Carbon stell*



Gambar.F.10. Detail *nozzle*

1. Diameter saluran masuk umpan padatan

*Coulson and Richardson vol.6, 1983, P.221, Eq 5.15*

$$d, optimum = 293.G^{0.53}.\rho^{-0.37}$$

Keterangan :

d = diameter saluran umpan solid

G = kecepatan umpan masuk = 1355,4019 kg/jam = 0,3765 kg/s

$\rho$  = densitas solid = 57572,7043 kg/m<sup>3</sup>

maka :

d optimum = 3,0251 mm = 0,1191 in

d optimum standart = 0,125 in

Spesifikasi pipa dari *tabel 11. P.844, Kern, 1980* :

NPS = 0,125 in

Sch = 40

ID = 0,269 in

OD = 0,405 in

A = 0,058 in<sup>2</sup>

Spesifikasi pipa dari (*Brownel and Young, 1959, app F p.349*), dipilih

ukuran standart (Sch 40) :

size of nozzle = 0,75

OD = 1,313 in

Flanged Nozzle = Coupling

DR = 1,4375 in

*Distance from bottom of tank to center of nozzle :*

*regular, type H = 4*

*low, type G = 3*

## 2. Diameter saluran masuk umpan air

$$d, \textit{ optimum} = 293.G^{0,53} \cdot \rho^{-0,37}$$

*Coulson and Richardson vol.6, 1983, P.221, Eq 5.15*

Keterangan :

d = diameter saluran umpan liquid

G = kecepatan umpan masuk = 7888,4390 kg/jam = 2,1912 kg/s

$\rho$  = densitas liquid = 980,3747 kg/m<sup>3</sup>

maka :

d optimum = 34,7230 mm = 1,3670 in

d optimum standart = 1,5 in

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

NPS = 1,5 in

Sch = 40

$$ID = 1,61 \text{ in}$$

$$OD = 1,9 \text{ in}$$

$$A = 2,04 \text{ in}^2$$

Laju alir volumetrik ( $F_v$ ) :

$$F_v = G/\rho_{air}$$

$$= 8,0464 \text{ m}^3/\text{jam} = 0,0022 \text{ m}^3/\text{s} = 136,3939 \text{ in}^3/\text{s}$$

Kecepatan aliran ( $v$ ) :

$$v = F_v/A$$

$$= 66,8598 \text{ in/s} = 1,6982 \text{ m/s}$$

Spesifikasi pipa dari (*Brownel and Young, 1959, app F p.349*), dipilih ukuran standart (Sch 40) :

$$\text{size of nozzle} = 1,5$$

$$OD = 2,2 \text{ in}$$

*Flanged Nozzle = Coupling*

$$DR = 2,375 \text{ in}$$

*Distance from bottom of tank to center of nozzle :*

$$\text{reguler, type } H = 6$$

$$\text{low, type } G = 3$$

### 3. Diameter saluran keluar produk

*Coulson and Richardson vol.6, 1983, P.221, Eq 5.15*

$$d, \text{ optimum} = 293.G^{0,53} \cdot \rho^{-0,37}$$

Keterangan :

d = diameter saluran produk

G = kecepatan umpan masuk = 9243,8409 kg/jam = 2,5677 kg/s

$\rho$  = densitas mix = 1017,5123 kg/m<sup>3</sup>

maka :

d optimum = 37,2511 mm = 1,4666 in

d optimum standart = 1,5 in

Spesifikasi pipa dari *tabel 11, P.844, Kern, 1980*

NPS = 1,5 in

Sch = 40

ID = 1,61 in

OD = 1,9 in

A = 2,04 in<sup>2</sup>

Laju alir volumetrik (Fv) :

Fv = G/ $\rho$ mix

$$= 9,0847 \text{ m}^3/\text{jam} = 0,0025 \text{ m}^3/\text{s} = 153,9958 \text{ in}^3/\text{s}$$

Kecepatan aliran (v) :

$$v = Fv/A$$

$$= 75,4881 \text{ in/s} = 1,9174 \text{ m/s}$$

Spesifikasi pipa dari (*Brownel and Young, 1959, app F p.349*), dipilih ukuran standart (Sch 40) :

$$\text{size of nozzle} = 1,5$$

$$\text{OD} = 2,2 \text{ in}$$

*Flanged Nozzle = Coupling*

$$\text{DR} = 2,375 \text{ in}$$

*Distance from bottom of tank to center of nozzle :*

*reguler, type H = 6*

*low, type G = 3*

#### 4. Diameter saluran air pendingin masuk

*Coulson and Richardson vol.6, 1983, P.221, Eq 5.15*

$$d, \text{ optimum} = 293 \cdot G^{0,53} \cdot \rho^{-0,37}$$

Keterangan :

d = diameter saluran produk

G = kecepatan umpan masuk = 18370,0373 kg/jam = 5,102788 kg/s

$\rho$  = densitas air = 995,7000 kg/m<sup>3</sup>

maka :

$$d_{\text{optimum}} = 54,0379 \text{ mm} = 2,1275 \text{ in}$$

$$d_{\text{optimum standart}} = 2,5 \text{ in}$$

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

$$\text{NPS} = 2,5 \text{ in}$$

$$\text{Sch} = 40$$

$$\text{ID} = 2,469 \text{ in}$$

$$\text{OD} = 2,88 \text{ in}$$

$$A = 4,79 \text{ in}^2$$

Laju alir volumetrik ( $F_v$ ) :

$$F_v = G/\rho_{\text{air}}$$

$$= 18,4494 \text{ m}^3/\text{jam} = 0,0051 \text{ m}^3/\text{s} = 312,7358 \text{ in}^3/\text{s}$$

Kecepatan aliran ( $v$ ) :

$$v = F_v/A$$

$$= 65,2893 \text{ in/s}$$

$$= 1,6583 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih

ukuran standart (Sch 40) :

$$\text{size of nozzle} = 3$$

$$\text{OD} = 4 \text{ in}$$



Flanged Nozzle = Coupling

DR = 4,125 in

Distance from bottom of tank to center of nozzle :

regular, type H = 8

low, type G = 5

#### 5. Diameter saluran air pendingin keluar

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

$$d, optimum = 293.G^{0,53}.\rho^{-0,37}$$

Keterangan :

d = diameter saluran air pendingin keluar

G = kecepatan umpan masuk = 18370,0373 kg/jam = 5,102788 kg/s

$\rho$  = densitas liquid = 995,7000 kg/m<sup>3</sup>

maka :

d optimum = 54,0379 mm = 2,1275 in

d optimum standart = 2,5 in

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

NPS = 2,5 in

Sch = 40

ID = 2,469 in

$$OD = 2,88 \text{ in}$$

$$A = 4,79 \text{ in}^2$$

Laju alir volumetrik ( $F_v$ ) :

$$F_v = G/\rho_{air}$$

$$= 18,449370 \text{ m}^3/\text{jam} = 0,005124825 \text{ m}^3/\text{s} = 312,7358 \text{ in}^3/\text{s}$$

Kecepatan aliran ( $v$ ) :

$$v = F_v/A$$

$$= 65,2893 \text{ in/s}$$

$$= 0,0077 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih ukuran standart (Sch 40) :

size of nozzle = 3

$$OD = 4 \text{ in}$$

Flanged Nozzle = Coupling

$$DR = 4,125 \text{ in}$$

Distance from bottom of tank to center of nozzle :

reguler, type H = 8

low, type G = 5

## I. Perancangan penyangga Reaktor

### 1. Berat shell

$$ID = 64,0852 \text{ in} = 5,3404 \text{ ft}$$

$$OD = 66 \text{ in} = 5,5000 \text{ ft}$$

$$H = 128,1705 \text{ in} = 10,6809 \text{ ft}$$

$$\rho = \text{densitas carbon stell (Foust, App. D-10, p.742)}$$

$$= 489,0000 \text{ lb/ft}^3 = 7833,0465 \text{ kg/m}^3$$

maka :

$$\text{Berat shell} = \frac{1}{4} \pi (OD^2 - ID^2) H \rho$$

$$= 7091,9754 \text{ lb}$$

$$= 3216,8633 \text{ kg}$$

### 2. Berat head

$$OD = 66 \text{ in} = 5,5000 \text{ ft}$$

$$sf = 2 \text{ in} = 0,1667 \text{ ft}$$

$$icr = 4 \text{ in} = 0,3333 \text{ ft}$$

$$th = 0,21 \text{ in} = 0,0178 \text{ ft}$$

$$\rho = 489,0000 \text{ lb/ft}^3 \text{ (Foust, App. D-10, p.742)}$$

Untuk  $th < 1$  in perkiraan blank diameter (bd) adalah :

$$bd = OD + OD/42 + 2 \cdot sf + 2/3 \text{ icr (Brown and young, Eq. 5-12, p.88)}$$

$$= 74,238 \text{ in}$$

$$= 6,187 \text{ ft}$$

$$\text{Berat dish} = 2(1/4\pi \cdot bd^2 \cdot th \cdot \rho_{\text{steel}})$$

$$= 523,0591 \text{ lb}$$

$$= 237,2554 \text{ kg}$$

### 3. Berat jaket

$$V_j = 271,0717 \text{ ft}^3$$

$$\rho = 995,7000 \text{ lb/ft}^3$$

maka :

$$\text{berat jaket} = 269906,1332 \text{ lb} = 122427,2628 \text{ kg}$$

### 4. Berat Opening

#### a. Berat nozzle 1

$$\text{ukuran} = 0,125 \text{ in}$$

Appendix untuk menentukan ukuran standard

$$\text{Diambil, ukuran standart} = 0,5 \text{ in}$$

$$\text{Berat} = 2 \text{ lb}$$

#### b. Berat nozzle 2

$$\text{ukuran} = 1,5 \text{ in}$$

$$\text{berat} = 4 \text{ lb}$$

#### c. Berat nozzle 3

ukuran = 1,5 in

berat = 4 lb

d. Berat nozzle 4

ukuran = 2,5 in

diambil, ukuran standart = 2,5 in

berat = 8 lb

e. Berat nozzle 5

ukuran = 2,5 in

diambil, ukuran standart = 2,5 in

berat = 8 lb

Berat total nozzle = 26 lb

= 11,7934 kg

f. Berat manhole

manhole 20 in = 428,00 lb (Megyesy, pp. 413)

Berat tutup = 29,22 lb (Megyesy, pp. 384)

Berat manhole = Manhole 20 in + Berat tutup

= 457,22 lb

= 207,39 kg

Berat total Opening = Berat total nozzle + Berat manhole

$$= 483,2200 \text{ lb} = 219,1847 \text{ kg}$$

5. Berat sistem pengaduk

a. Berat impeller

$$D_i = 0,5426 \text{ m} = 1,7801 \text{ ft}$$

$$W = 0,1085 \text{ m} = 0,3560 \text{ ft}$$

$$t_a = 0,1085 \text{ m} = 0,3560 \text{ ft}$$

$$\rho = 489 \text{ lb/ft}^3$$

Berat total six blade :

$$\text{Berat impeller} = 6 \left( \frac{D_i}{2} \right) \cdot W \cdot t_a \cdot \rho$$

$$= 331,0212 \text{ lb}$$

b. Berat sumbu

$$L = 3,6758 \text{ m} = 12,0598 \text{ ft}$$

$$d = 3,0366 \text{ cm} = 0,0304 \text{ m} = 0,0996 \text{ ft}$$

$$\rho = 489 \text{ lb/ft}^3$$

$$\text{Berat sumbu} = \frac{1}{4} \cdot \pi \cdot d^2 \cdot L \cdot \rho$$

$$= 45,9490 \text{ lb}$$

Berat total = Berat impeller + berat sumbu

$$= 376,9702 \text{ lb}$$

$$= 170,9907 \text{ kg}$$

## 6. Berat Baffle

$$\text{Panjang Baffle (H)} = 2,3077 \text{ m} = 7,5712 \text{ ft}$$

$$\text{Lebar baffle (w)} = 0,1989 \text{ m} = 0,6525 \text{ ft}$$

$$\text{Tebal baffle (W)} = 0,1085 \text{ m} = 0,3560 \text{ ft}$$

$$\text{jumlah} = 4 \text{ buah}$$

$$\rho = 489 \text{ lb/ft}^3$$

$$\text{Berat total baffle} = \text{jumlah} \times \text{tebal} \times \text{lebar} \times \text{tinggi} \times \rho$$

$$= 3440,4886 \text{ lb}$$

$$= 1560,5781 \text{ kg}$$

## 7. Berat fluida dalam reaktor

### a. Berat bahan baku

$$\text{Laju alir massa} = 9243,8409 \text{ kg/jam}$$

$$\text{Waktu tinggal} = 40 \text{ menit} = 0,67 \text{ jam}$$

$$\text{Berat bahan baku} = \text{laju alir massa} \times \text{waktu tinggal}$$

$$= 6162,5606 \text{ kg}$$

$$= 13586,1043 \text{ lb}$$

### b. Berat pendingin

$$\text{Volume jaket} = 271,0717 \text{ ft}^3$$

$$\rho \text{ pendingin} = 995,7000 \text{ lb/ft}^3$$

$$\text{Berat steam} = V_j \times \rho \text{ steam}$$

$$= 269906,1332 \text{ lb}$$

$$= 122427,2628 \text{ kg}$$

$$\text{Berat total fluida} = \text{Berat bahan baku} + \text{Berat steam}$$

$$= 283492,2375 \text{ lb}$$

$$= 128589,8110 \text{ kg}$$

#### 8. Berat reaktor

$$\begin{aligned} \text{Berat mati reaktor} &= \text{Berat shell} + \text{berat head} + \text{berat jaket} + \text{Berat} \\ &\quad \text{opening} + \text{berat pengaduk} + \text{berat baffle} + \text{berat} \\ &\quad \text{fluida dalam reaktor} \end{aligned}$$

$$= 565314,0840 \text{ lb}$$

$$= 256421,9460 \text{ kg}$$

Maka :

Desain sistem penyangga

$$\text{Berat untuk perancangan} = 1,2 \times \text{Berat mati reaktor}$$

$$= 678376,9008 \text{ lb}$$

$$= 307706,3352 \text{ kg}$$



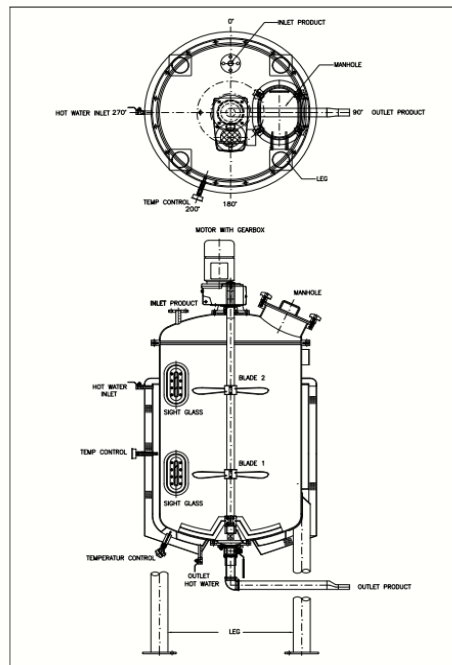
## Desain Proses Reaktor-01

Reaktor-01

Fungsi : Sebagai tempat mereaksikan  $\text{Ca(OH)}_2$  dengan gas  $\text{CO}_2$  untuk menghasilkan  $\text{CaCO}_3$

Type : Reaktor Alir Tangki Berpengaduk Slurry

Gambar :



Sumber : Bapak Rumadi

Kondisi Operasi :

$$T = 35 \text{ }^\circ\text{C} = 308,15 \text{ K}$$

$$P = 2 \text{ atm} = 202650 \text{ Pa} = 29,3918 \text{ Psia}$$

$$R = 0,082057 \text{ L.atm/kmol.K} = 8,3144 \text{ m}^3.\text{Pa/kmol.K} \quad (\text{Konstanta gas ideal})$$

$$\rho \text{ campuran} = 1030,2760 \text{ kg/m}^3 = 64,2892 \text{ lb/ft}^3$$

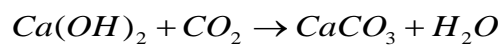
$$\text{Laju Alir Massa} = 10004,9287 \text{ kg/jam}$$

$$\text{Waktu Tinggal} = 2,4366 \text{ jam}$$

$$\text{Over Desain} = 20\%$$

$$\text{Konversi} = 95\%$$

Reaksi yang terjadi adalah :



#### A. Menentukan Densitas Reaktan

##### 1. Mencari densitas reaktan

> Komposisi reaktan (fase aqueous)

$$\rho \text{ campuran} = 1026,7958 \text{ kg/m}^3 = 1,0268 \text{ gr/cm}^3 = 0,0371 \text{ lb/in}^3$$

$$\rho \text{ solid} = 43426,2667 \text{ kg/m}^3 = 43,4263 \text{ gr/cm}^3$$

$$\rho \text{ fluida} = 1051,6619 \text{ kg/m}^3 = 1,0517 \text{ gr/cm}^3$$

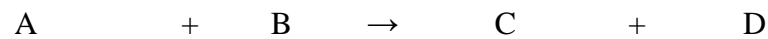
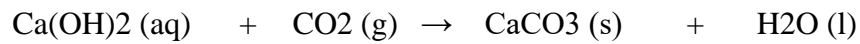
$$\mu \text{L} = 0,6968 \text{ cP} = 0,0006968 \text{ kg/m.s}$$

> Komposisi reaktan (fase gas)

$$\rho = 3,4802 \text{ kg/m}^3 = 0,0035 \text{ gr/cm}^3$$

## B. Menentukan Kinetika Reaksi

Reaksi :



### 1. Konsentrasi Reaktan

#### a. Konsentrasi $\text{Ca(OH)}_2$

Konsentrasi  $\text{Ca(OH)}_2$  menggunakan kelarutan  $\text{Ca(OH)}_2$  terhadap  $\text{H}_2\text{O}$  Karena Transfer massa berjalan dari Padat - Cair dengan medium yang digunakan air. Maka konsentrasi yang digunakan yaitu konsentrasi berdasarkan kelarutan padatan ke cairan.

Table 2-122, Perry page:2-216

Solubilities of  $\text{Ca(OH)}_2$  in water at Various Temperatures

Coumpound	Suhu (oC)	Solubility (gr/ 100 cm <sup>3</sup> )
Ca(OH) <sub>2</sub>	0	1,85
	10	0,176
	20	0,165
	30	0,153
	40	0,141
	50	0,128
	60	0,116
	70	0,106
	80	0,094
	90	0,085
	100	0,077

Kelarutan 35 °C = 0,147 gr/ 100 cm<sup>3</sup>

= 0,00147 gr/cm<sup>3</sup>

$$= 1,47 \text{ gr/L}$$

$$CA = \text{Kelarutan Ca(OH)}_2 / \text{BM}$$

$$CA = (1 \text{ gr/L}) / (74 \text{ gr/mol})$$

$$CA = 0,0199 \text{ mol/L}$$

$$= 0,0199 \text{ kmol/m}^3$$

b. Konsentrasi CO<sub>2</sub>

Konsentrasi CO<sub>2</sub> menggunakan kelarutan CO<sub>2</sub> terhadap H<sub>2</sub>O Karena Transfer massa berjalan dari Gas-Cair dengan medium yang digunakan air. Maka konsentrasi yang digunakan yaitu konsentrasi berdasarkan kelarutan Gas ke cair.

Table 2-122, Perry page:2-216

Solubilities of CO<sub>2</sub> in water at Various Temperatures

Coumpound	Suhu (oC)	Solubility (gr/ 100 cm <sup>3</sup> )
CO <sub>2</sub>	0	0,3346
	10	0,2318
	20	0,1688
	30	0,1257
	40	0,0973
	50	0,0761
	60	0,0576
	70	
	80	
	90	
	100	0

$$\text{Kelarutan } 35 \text{ }^\circ\text{C} = 0,1115 \text{ 100 gr/ 100 cm}^3$$

$$= 0,001115 \text{ gr/cm}^3 = 1,115 \text{ gr/L}$$

$$CB = \text{Kelarutan CO}_2 / \text{BM}$$

$$CB = (1,1 \text{ gr/L}) / (44 \text{ gr/mol})$$

$$CB = 0,0253 \text{ mol/L}$$

$$= 0,000025 \text{ kmol/L} = 0,0253 \text{ kmol/m}^3$$

## 2. Transfer massa

### a. Pengaruh perubahan kecepatan aliran gas CO2

Persamaan hubungan antara  $\ln k_{1ag}$  dan  $\ln k_s$  dengan  $\ln V$

$$k_{sas} = 0,8744V^{0,6244}$$

$$k_{1ag} = 0,9616V^{0,6028}$$

Kecepatan aliran gas CO2 : 34,0127-60,5503 cm/s

Diambil :  $V = 60,5503 \text{ cm/s} = 0,605503 \text{ m/s}$

### b. Kecepatan transfer massa dari padat - cair

$$N_A = k_{sas} (CA^* - CA)$$

Dimana :

NA = Kecepatan transfer massa padat-cair

ksas = Koefisien transfer massa padar-cair

CA\* = Konsentrasi bulk Ca(OH)2 terhadap H2O

CA = Konsentrasi Ca(OH)2

maka :

$$CA^* = (\text{mol Ca(OH)}_2) / (\text{mol Ca(OH)}_2 + \text{mol H}_2\text{O})$$

$$= 0,0486 \text{ kmol/m}^3$$

$$k_{sas} = 0,6392 \text{ m/s} = 2301,2620 \text{ m/jam}$$

Jadi :

$$N_A = k_{sas} (CA^* - CA)$$

$$N_A = 66,1470 \text{ kmol/m}^2 \cdot \text{jam}$$

- c. Kecepatan transfer massa dari gas - cair

Hubungan Kesetimbangan Uap-Cair :

$$CB^* = \frac{P_B}{H}$$

Diketahui :

(Pers. Hukum Boyle Gay-Lussac)

$$\text{Rumus Gas Ideal : } P_B = \frac{nRT}{V}$$

Kecepatan transfer massa dari gas - cair :

$$N_B = k_{1ag} (CB^* - CB)$$

Dimana :

NB = Kecepatan transfer massa gas-cair

k<sub>1ag</sub> = Koefisien transfer massa gas-cair

CB\* = Konsentrasi CO<sub>2</sub> dari Hubungan Kesetimbangan Uap - Cair

CB = Konsentrasi CO<sub>2</sub>

PB = Tekanan parsial CO<sub>2</sub> dalam air (atm)

H = Konstanta Henry pada T = 35 °C

$$= 0,0000164 \text{ atm}\cdot\text{m}^3/\text{mol fraksi CO}_2$$

n = Jumlah mol CO<sub>2</sub> = 20,1290 kmol/jam

R = Konstanta gas ideal = 0,08206 m<sup>3</sup>·atm/kmol.K

T = 35 °C = 308,15 K

V = m/ρ

$$= 254,4898 \text{ m}^3/\text{jam}$$

Maka :

$$CB^* = (2,00007312 \text{ atm}) / (0,0000164 \text{ atm}\cdot\text{m}^3/\text{mol fraksi CO}_2)$$

$$CB^* = 121955,6780 \text{ mol/m}^3$$

$$CB^* = 121,9557 \text{ kmol/m}^3$$

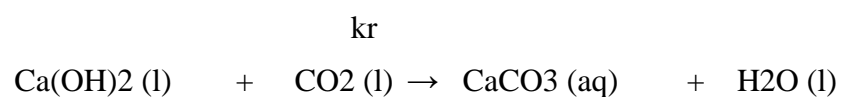
$$k_{lag} = 0,7106 \text{ m/s} = 2558,3306 \text{ m/jam}$$

Jadi :

$$NB = 311938,1091 \text{ kmol/m}^2\cdot\text{jam}$$

d. Kecepatan reaksi

Reaksi berlangsung pada fase cair dengan reaksi :



Kecepatan reaksi CO<sub>2</sub> terlarut dan Ca(OH)<sub>2</sub> terlarut difase cair pada orde 2, yaitu :

$$-(r_A) = k_r \cdot C_A \cdot C_B$$

Hubungan antara konstanta kecepatan reaksi (kr) terhadap suhu pada kisaran 30-50 °C dapat didekati dengan persamaan archenius yaitu :

$$k_r = 1771000e^{-2321,4/T}$$

$$kr = 947,390 \text{ cm}^3/\text{mol/s}$$

$$= 0,9474 \text{ m}^3/\text{kmol/s}$$

$$= 3410,6038 \text{ L/mol/jam}$$

Maka :

$$-(r_A) = k_r \cdot C_A \cdot C_B$$

$$-(r_A) = 1,7169 \text{ mol/(L.jam)}$$

$$-(r_A) = 1,7169 \text{ kmol/(m}^3\text{.jam)}$$

### 3. Menentukan Volume reaktor

#### a. Laju Alir Umpan

$$\text{Laju alir volumetrik umpan (Fv)} = W/\rho$$

$$= 9,7109 \text{ m}^3/\text{jam}$$

$$= 9710,9212 \text{ L/jam}$$

#### b. Menentukan volume tangki



Neraca massa A di dalam reaktor pada steady state :

$$[\text{Rate of flow of A input}] - [\text{Rate of flow of A Output}] -$$

$$[\text{Rate of reaction}] = [\text{Rate of accumulation}]$$

$$F_{A0} - F_A - (-r_A)V = 0$$

$$F_{A0} - F_A = (-r_A)V$$

$$V = (F_{A0} - F_A) / (-r_A)$$

Dimana :

$$F_A = F_{A0}(1-X_A)$$

$$F_A = F_{A0} - F_{A0}.X_A$$

$$F_{A0} - F_A = F_{A0}.X_A$$

Jadi :

$$V = (F_{A0}.X_A) / (-r_A) \text{ (dari Fogler,1999 p.39)}$$

$$\text{Untuk CSTR : } (V) = F_{A0}.X / (-r_A)$$

$$\text{Dimana : } F_{A0} = 21,1884 \text{ kmol/jam}$$

$$X = 95\%$$

$$(-r_A) = 1,7169 \text{ kmol/m}^3.\text{jam}$$

Maka :

$$V = 11,7242 \text{ m}^3 = 413,9904 \text{ ft}^3$$

$$\text{Faktor keamanan / Over Desain} = 20\%$$

$$V_{\text{reaktor}} = 14,0691 \text{ m}^3 = 835,6018 \text{ ft}^3$$

waktu tinggal :

$$\tau = V/F_v$$

$$= 1,4488 \text{ jam}$$

$$= 86,9272 \text{ menit}$$

## B. Dimensi Reaktor

### 1. Menentukan Dimensi Reaktor

Untuk operasi dengan tekanan dalam rentang 1 atm (15 psig) sampai 14 atm (200 psig), menggunakan : Torispherical Flanged and Dished Head (Brownell n Young, 1959: hal 92)

#### a. Diameter dan tinggi reaktor

- Diketahui  $V = 11,7242 \text{ m}^3$

$$= 413,9904 \text{ ft}^3$$

(Over design : 20%)

$$V_{\text{reaktor}} = 14,0691 \text{ m}^3$$

$$= 835,5079 \text{ ft}^3$$

Pengambilan H/D diusahakan mendekati 1, karena jika H/D terlalu besar atau terlalu kecil maka :

> Pengadukan tidak sempurna

> Distribusi panas tidak merata

Dipilih :

(Brownell,1959)

$$H/D = 2$$

$$H = 2D$$

$$\text{Volume shell} = \frac{\pi}{4} 2D^3$$

$$14,0691 = \frac{\pi}{2} D^3$$

$$D = \sqrt[3]{\frac{2 \times V_{shell}}{\pi}}$$

$$D = 2,0771 \text{ m}$$

$$= 81,7752 \text{ in}$$

Jumlah reaktor yang digunakan : 1 RATB

Dengan :

$$V_{shell} = 23,6616 \text{ m}^3$$

$$D_{shell} = 2,0771 \text{ m} = 81,7750 \text{ in} = 6,8146 \text{ ft}$$

$$H_{shell} = 4,1542 \text{ m} = 163,5500 \text{ in} = 13,6292 \text{ ft}$$

Dipilih standart ;

$$D_{shell} = 2,1 \text{ m} = 81,8 \text{ in} = 6,8 \text{ ft}$$

$$H_{shell} = 4,2 \text{ m} = 163,5 \text{ in} = 13,6 \text{ ft}$$

## 2. Menentukan Tinggi Cairan

$$HL = (V_{shell}) / (\pi D^2/4)$$

$$HL = 4,1542 \text{ m} = 163,5500 \text{ in} = 13,6292 \text{ ft}$$

### 3. Menentukan Tekanan Desain

$$\text{Tekanan operasi (Pops)} = 2 \text{ atm} (29,4 \text{ psia})$$

Keterangan :

$$g = \text{Percepatan gravitasi} = 32,174 \text{ ft/det}^2$$

$$g_c = \text{Faktor konversi percepatan gravitasi} = 32,174 \text{ g.cm/gf.det}^2$$

$$\text{Phidrostatik} = \frac{\rho_{mix} \left( \frac{g}{g_c} \right) H_L}{144}$$

$$= 7,2361 \text{ psia}$$

$$P_{abs} = P_{operasi} + P_{hidrostatik}$$

$$= 29,4 + 7,2361$$

$$= 36,6279 \text{ psia}$$

Tekanan desain 5-10% diatas tekanan kerja absolute (Coulson, 1988:637)

Tekanan desain yang dipilih 10% diatasnya

$$P_{desain} = 1,1 \times P_{abs}$$

$$= 1,1 \times 36,6279 \text{ psia}$$

$$= 40,2907 \text{ psia}$$

$$= 25,5907 \text{ psig}$$

### 4. Menentukan Ketebalan dinding reaktor

Tipe material penyusun reaktor adalah Carbon Steel SA-229. Hal ini disebabkan:

- > Mempunyai allowable stress yang besar
- > Struktur kuat
- > Harga yang relatif lebih murah
- > Dapat menangani Ca(OH)<sub>2</sub>

(pers 14.34 Brownell, 1959:275)

Ketebalan dinding shell :

$$t_s = \frac{P \cdot r_i}{f \cdot E - 0,6P} + C$$

Keterangan :

$t_s$  = tebal shell, in

$r_i$  = jari-jari shell =  $D/2 = 1,0385 \text{ m} = 48,6241 \text{ in} = 4,0520 \text{ ft}$

$f$  = Allowable stress untuk Carbon Steel SA 229 = 18750 psi

(Table 13.1 Brownell, 1959:251)

$E$  = Joint efisiensi tipe double-butt weld = 80% (Table 13.2 Brownell, 1959:254)

$C$  = Corrosian allowance = 0,0125 in/yr (Table 6. Timmerhaus, 1991:542)

= 0,125 in/10 yr

$P = \text{tekanan desain} = 25,5907 \text{ psig}$

maka :

$$t_s = \frac{P \cdot r_i}{f \cdot E - 0,6P} + C$$

$$t_s = 0,2080 \text{ in}$$

Diambil,  $t_s$  standart =  $5/16 \text{ in} = 0,3125 \text{ in}$

5. Menentukan Diameter luar tangki

Standarisasi OD :

$$OD = ID + 2 \cdot t_s$$

$$= 82,4000 \text{ in}$$

Diambil OD standart = 102 in (Table 5.7 Brownell & young, 1959:91)

6. Perancangan Head Tangki

$$th = \frac{P \cdot r_c \cdot W}{2 \cdot f \cdot E - 0,2 \cdot P} + C$$

Bentuk : Torispherical dished head

Digunakan untuk tangki dengan tekanan dalam rentang 15 psig (1,020689 atm) - 200 psig (13,60919 atm). Menentukan dimensi tutup atas dan bawah :

Ketebalan torispherical head (Pers. 7.77 Brownell & Young, 1959)

Keterangan :

th = Tebal head, in

W = Faktor intensifikasi stress

f = Allowable stress untuk Carbon Steel SA 229 grade C = 18750 psi

(Table 13.1 Brownell, 1959:251)

E = Joint efisiensi tipe double-butt weld = 80% (Table 13.2 Brownell, 1959:254)

C = Corrosian allowance = 0,0125 in/yr (Table 6. Timmerhaus,1991:542)

= 0,125 in/10 yr

P = Tekanan desain = 25,5907 psig

Untuk OD = 102 in (Table 5.7 Brownell & young, 1959:91)

$$th = \frac{P \cdot r_c \cdot W}{2 \cdot f \cdot E - 0,2 \cdot P} + C$$

inside corner radius (icr) = 6,125 in

crown radius (rc) = 96 in

$$W = \frac{1}{4} \left( 3 + \sqrt{\frac{rc}{icr}} \right)$$

W = 1,7397 in

Jadi :

th = 0,27 in

Digunakan tebal head standard = 5/16 in

Tebal bottom = tebal head (th) = 0,3125 in

Untuk th = 3/8 in, maka sf = 1,5 - 3 in (Tabel 5.6 Brownell, 1959:88)

Dipilih,  $sf = 1,5 \text{ in}$

$$AB = (ID/2) - icr$$

$$= 34,7625 \text{ in}$$

$$BC = rc - icr$$

$$= 90 \text{ in}$$

$$\text{Depth of Dish (b)} = r_c - \sqrt{BC^2 - AB^2}$$

$$= 13,1201 \text{ in}$$

$$\text{Tinggi Head (OA)} = th + b + sf$$

$$= 14,9326 \text{ in}$$

Jadi :

$$\text{Tinggi dished head (Hd)} = OA$$

$$= 14,9326 \text{ in} = 1,2444 \text{ ft} = 0,3793 \text{ m}$$

$$\text{Tinggi cairan di shell (HL,S)} = HL - OA$$

$$= 179,5637 \text{ in} = 14,9636 \text{ ft} = 4,5609 \text{ m}$$

$$\text{Tinggi total reaktor (Hreaktor)} = Hs + 2 \cdot Hd$$

$$= 193,4151 \text{ in} = 16,1179 \text{ ft} = 4,9127 \text{ m}$$

$$\text{Volume pada sf (Vsf)} = (\pi/4) \cdot D^2 \cdot sf$$

$$= 7874,1164 \text{ in}^3 = 4,5568 \text{ ft}^3 = 0,1290 \text{ m}^3$$



$$\begin{aligned} \text{Volume head torispherical (Vd)} &= 0,000049 \text{ ID}^3 \text{ (pers. 5.11. Brownell,} \\ & \quad \text{1959:88)} \\ &= 26,7952 \text{ in}^3 = 0,0155 \text{ ft}^3 = 0,0004 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Volume sebuah head} &= 2(\text{Vd} + \text{Vsf}) \\ &= 15801,8233 \text{ in}^3 = 9,1446 \text{ ft}^3 = 0,2588 \text{ m}^3 \end{aligned}$$

$$\text{Vreaktor} = \text{Vshell} + \text{Vhead}$$

$$\text{Vreaktor} = 14,3278 \text{ m}^3 = 3785,0161 \text{ gallon}$$

## C. Desain Sistem Pengaduk

### 1. Dimensi Pengaduk

Digunakan jenis six pitched blade turbine. Karena dapat digunakan untuk campuran berviskositas  $< 10.000 \text{ cp}$  (Geankoplis, 1993:143) dan cocok untuk pengadukan suspensi solid (Wallas, 1990:298). Berikut ini dijabarkan geometrinya:

$$\text{Dt/Di} = 3 \text{ (Brown, 1950:507)}$$

$$\text{Zi/Di} = 1 \text{ (Brown, 1950:507)}$$

$$\text{w/Di} = 0,17 \text{ (Brown, 1950:507)}$$

$$\text{r} = 0,25 \text{ Di (Metcalf and Eddy, 1991)}$$

$$\text{Offset 1} = 0,5 \text{ Di (Wallas, 1990:288)}$$

$$\text{Offset 2} = 0,17 \text{ w (Wallas, 1990:288)}$$

$$D_d = 0,67 D_i \text{ (Geankoplis, 1993:144)}$$

$$W/D_i = 0,2 \text{ (Geankoplis, 1993:144)}$$

Keterangan :

$D_i$  = Diameter impeller, m

$D_t$  = Diameter tangki, m

$Z_i$  = Tinggi impller dari dasar tangki, m

$w$  = Lebar baffle, m

$W$  = Tebal baffle, m

$D_d$  = Diameter batang penyangga impeller, m

$r$  = impeller blade length, m

Offset 1 = Jarak baffle dari dasar tangki, m

Offset 2 = Jarak baffle dari permukaan cairan, m

Dimensi pengaduk adalah :

$$D_i = (1/3) \times D_t = 0,6924 \text{ m}$$

$$Z_i = 1 \times D_i = 0,6924 \text{ m}$$

$$w = 0,17 \times D_i = 0,1177 \text{ m}$$

$$r = 0,25 \times D_i = 0,2058 \text{ m}$$

$$\text{Offset 1} = 0,5 \times D_i = 0,3462 \text{ m}$$

$$\text{Offset 2} = 0,17 \times w = 0,0200 \text{ m}$$

$$D_d = 0,67 \times D_i = 0,4639 \text{ m}$$

$$W = 0,2 \times D_i = 0,1647 \text{ m}$$

$$\text{Jumlah baffle} = 4$$

$$\text{Panjang baffle} = H_{L,S} - (\text{Offset 1} + \text{Offset 2}) = 4,2 \text{ m}$$

## 2. Kecepatan Putaran Pengaduk

- a. Menentukan jumlah pengaduk

$$\text{Jumlah pengaduk} = WELH/ID$$

Keterangan :

$$WELH = \text{water equivalent liquid height} = H_{L,S} \times sg$$

ID = Diameter dalam reaktor , in

sg = specific height

$$sg = \rho_{\text{campuran}} / \rho_{\text{air}}$$

$$= 1,0303$$

maka :

$$WELH = 185,0002 \text{ in}$$

sehingga:

$$\text{Jumlah impeller} = 2 \text{ buah}$$

Kecepatan putaran pengaduk :

$$N = \frac{600}{\pi * Di(ft)} \sqrt{\frac{WELH}{2 * Di(in)}}$$

Keterangan :

N = Kecepatan putaran pengaduk

Di = Diameter impeller = 0,6924 m = 27,2584 in = 2,2715 ft

WELH = Water equivalent liquid height = 185,0002 in

Maka :

N = 154,9614 rpm = 2,5827 rps

### 3. Daya pengaduk

(pers 9-24 Mc.Cabe,1993)

$$P = \frac{K_T \cdot \rho \cdot N^3 \cdot D_i^5}{g_c}$$

Keterangan :

KT = konstanta untuk impeller = 1,63 (Table 9.2 Mc. Cabe

1993:252)

Di = Diameter impeller = 0,6924 m = 2,272 ft

gc = percepatan gravitasi = 32,174 ft/s<sup>2</sup>

N = kecepatan putaran = 2,5827 rps

ρ = densitas fluida = 64,2892 lb/ft<sup>3</sup>

Maka :

$$P = \frac{K_T \cdot \rho \cdot N^3 \cdot D_i^5}{g c}$$

$$P = 6,1698 \text{ HP}$$

Daya yang hilang (Gland loss)

$$\text{Hilang (gland loss)} = 10\% \times \text{Daya Pengaduk} \quad (\text{MV. Joshi})$$

$$= 0,6170 \text{ hp}$$

Daya Input

$$\text{Daya Input} = \text{Kebutuhan daya pengaduk} + \text{Hilang (gland loss)}$$

$$= 6,1698 + 0,6170$$

$$= 6,7867 \text{ HP}$$

Efisiensi motor ( $\eta$ )

$$(\eta) = 80 \%$$

Daya motor yang digunakan:

$$P = 100/80 \times 0,6323 \text{ HP}$$

$$= 8,4834 \text{ HP}$$

Diambil, standart daya motor yang digunakan (P) = 10 HP (Standard

NEMA, Resa and Barrow, p.358)

#### 4. Panjang batang sumbu pengaduk (Axis lenght)

Axis length = tinggi total reaktor + jarak dari motor ke bagian bearing - jarak pengaduk dari dasar tangki

Axis length = 4,5252 m

Diameter sumbu =  $(Z_p \times 16)/\pi$

Keterangan :

$Z_p = T_m/f_s$

$T_m$  = Torsi maksimum

$Z_p$  = Shear stress

$f_s$  = Section of shaft cross section

Material sumbu yang digunakan adalah commercial cold rolled steel

Axis shear stress yang diizinkan,  $f_s = 550 \text{ kg/cm}^2$

Batasan elastis pada tegangan =  $2460 \text{ kg/cm}^2$

\* Menghitung  $T_m$

$T_m = (1,5 \text{ atau } 2,5) \times T_c$  Dari M.V Joshi, pers 14.10, hal 400

Diambil :

$T_m = 1,5 \cdot T_c$

$T_c = (P \cdot 75 \cdot 60)/(2\pi N) = 46,2412 \text{ kg, m}$

$T_m = 69,3619 \text{ kg, m}$

\*Menghitung  $Z_p$

$Z_p = T_m/f_s$

$$= 12,6112 \text{ cm}$$

\* Menghitung diameter sumbu (d)

$$d_3 = 84,3262 \text{ cm}$$

$$d = 4,3852 \text{ cm} = 0,0439 \text{ m}$$

#### D. Neraca Panas Reaktor-01

Kondisi Operasi :

$$T = 35 \text{ } ^\circ\text{C} \quad 308,15 \text{ K}$$

$$T_{\text{ref}} = 25 \text{ } ^\circ\text{C} \quad 298,15 \text{ K}$$

$$P = 2 \text{ atm}$$

a. Panas sensibel yang dibawa feed masuk (Q7) T= 35 oC :

Komponen	kg	n (kmol)	$\Delta H$ (kJ/kmol)	Q7 (kJ)
CaO	36,6975	0,6553	-32,5087	-21,3033
SiO	25,7526	0,4292	-415,3350	-178,2662
MgO	15,4516	0,3863	-336,4009	-129,9482
Fe <sub>2</sub> O <sub>3</sub>	2,7040	0,0169	-188,2093	-3,1808
Al <sub>2</sub> O <sub>3</sub>	5,7943	0,0568	-3156,2229	-179,2965
S	0,0901	0,0028	-1191,6080	-3,3564
P	0,0386	0,0012	182,5225	0,2274
H <sub>2</sub> O	7464,7784	414,7099	754,4608	312882,3560
Ca(OH) <sub>2</sub>	1567,9446	21,1884	21,4000	453,4326
Total	9119,251865			312820,6648

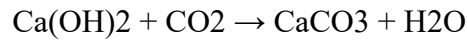
b. Panas sensibel yang dibawa CO<sub>2</sub> masuk (Q10) T= 35 oC :

Komponen	kg	n (kmol)	$\Delta H$ (kJ/kmol)	Q10 (kJ)
CO <sub>2</sub>	885,6768	20,1290	385,7638	7765,0471
Total				7765,0471

c. Panas Reaksi

Reaksi yang terjadi pada Reaktor (R-01)

Reaksi :



>> Panas reaksi pembentukan standar ( $\Delta H_f$ )

1. Entalpi pembentukan standar pada reaktan

Komponen	kmol	$\Delta H_f$ (kJ/kmol)	Q (kJ)
Ca(OH) <sub>2</sub>	21,1884	-868,0700	-18393,0500
CO <sub>2</sub>	20,1290	-393,5090	-7920,9501
Total			-26314,0001

2. Entalpi pembentukan standar pada produk

Komponen	kmol	$\Delta H_f$ (kJ/kmol)	Q (kJ)
CaCO <sub>3</sub>	20,1290	-1206,9200	-24294,1156
J H <sub>2</sub> O	20,1290	-285,8300	-5753,4775
Total			-30047,5931

a

$$\text{di : } \Delta H_{R,298} = \Delta H_f \text{ produk} - \Delta H_f \text{ reaktan}$$

$$\Delta H_{R,298} = -3733,5929 \text{ kJ}$$

>> Panas reaksi pada T = 35oC

1. Panas reaksi pada reaktan

Komponen	kmol	$\Delta H$ (kJ/kmol)	Q <sub>produk</sub> (kJ)
Ca(OH) <sub>2</sub>	21,1884	21,4000	453,4326
CO <sub>2</sub>	20,1290	385,7638	7765,0471
Total			8218,4797

2. Panas reaksi pada produk



Komponen	kmol	$\Delta H$ (kJ/kmol)	Qreaktan (kJ)
CaCO <sub>3</sub>	20,1290	-129,5189	-2607,0886
H <sub>2</sub> O	20,1290	754,4608	15186,5551
Total			12579,4665

Jadi :  $\Delta Q_{rx} = Q_{produk} - Q_{reaktan}$

$$\Delta Q_{rx} = 4360,9868 \text{ kJ}$$

Maka, Panas reaksi yang dihasilkan :

$$Q_{rx} = \Delta H_{R,298} + \Delta Q_{rx}$$

$$Q_{rx} = 627,3938 \text{ kJ (reaksi endotermis)}$$

d. Panas sensibel yang dibawa produk keluar (Q14) T= 35 °C

Komponen	kg	kmol	$\Delta H$ (kJ/kmol)	Q12 (kJ)
CaO	36,6975	0,6553	-32,5087	-21,3033
SiO <sub>2</sub>	25,7526	0,4292	-415,3350	-178,2662
MgO	15,4516	0,3863	-336,4009	-129,9482
Fe <sub>2</sub> O <sub>3</sub>	2,7040	0,0169	-188,2093	-3,1808
Al <sub>2</sub> O <sub>3</sub>	5,7943	0,0568	-3156,2229	-179,2965
S	0,0901	0,0028	-1191,6080	-3,3564
P	0,0386	0,0012	182,5225	0,2274
H <sub>2</sub> O	7827,1007	434,8389	754,4608	328068,9111
Ca(OH) <sub>2</sub>	78,3972	1,0594	21,4000	22,6716
CaCO <sub>3</sub>	2012,9019	20,1290	-129,5189	-2607,0886
Total	10004,9287			324969,3703

e. Panas yang diserap air pemanas pada jaket pemanas Reaktor-01

Panas Input (kJ)		Panas Output (kJ)	
Q7 =	312820,6648	Q12 =	324969,3703
Q10 =	7765,0471	Qrx =	627,3938
Sub Total =	320585,7118	Sub Total =	325596,7641
Beban Pemanas (Qs) =	5011,0522	Qs =	0,0000
Total =	325596,7641	Total =	325596,7641
Selisih	0,0000		

Jumlah pemanas yang dibutuhkan :

$$Q_s = 5011,0522 \text{ kJ}$$

Fluida Panas yang digunakan yaitu saturated steam pada  $T=100^\circ\text{C}$  dan  $P = 2 \text{ atm}$ .

$$\text{Entalpi saturated liquid (hf)} = 419,1 \text{ kJ/kg}$$

$$\text{Entalpi saturated vapor (hg)} = 2676,4 \text{ kJ/kg}$$

Jumlah steam yang dibutuhkan :

$$m = Q_s / (h_g - h_f)$$

$$= 2,2199 \text{ kg/jam}$$

Panas steam yang masuk (Qin) :

$$Q_{s \text{ in}} = m \times h_g$$

$$= 5941,4257 \text{ kJ}$$

Panas steam yang keluar (Qout) :

$$Q_{s \text{ out}} = m \times h_f$$

$$= 930,3735 \text{ kJ}$$

### E. Desain kebutuhan steam

Reaksi yang berlangsung dalam reaktor adalah reaksi endotermis. sehingga membutuhkan beban pemanas (steam). Perbedaan temperatur logaritmik rata-rata adalah :

Fluida Panas	Temperatur (°F)	Fluida Dingin	Selisih
212	Temp. Tinggi	95	117
212	Temp. Rendah	86	126
0		9	

$$\Delta T_{LMTD} = \frac{(T_2 - t_1) - (T_1 - t_2)}{\ln\left(\frac{(T_2 - t_1)}{(T_1 - t_2)}\right)}$$
$$= 121,4444 \text{ } ^\circ\text{F}$$

#### 1. Perhitungan Jaket Pemanas

Luas perpindahan panas yang tersedia

A = luas selimut reaktor + luas penampang bawah reaktor

$$A = \pi \cdot Do \cdot H_{L,S} + (\pi/4 \cdot Do^2)$$

Diketahui :

$$Do = 102 \text{ in}$$

$$= 8,5000 \text{ ft}$$

$$H_{L,S} = 14,9636 \text{ ft}$$

Sehingga :

$$A = \pi \cdot Do \cdot H_{L,S} + (\pi/4 \cdot Do^2)$$

$$= 456,0956 \text{ ft}^2$$

Luas perpindahan panas yang dibutuhkan dari tabel.8 (Kern, Process Heat Transfer ; hal 840) didapat Overall heat transfer UD dengan, hot fluid adalah steam dan cold fluid adalah aqueous dengan  $UD = 200 - 700$  Btu/jam.ft<sup>2</sup>.°F

Dipilih asumsi :

$$UD = 200 \text{ Btu/jam.ft}^2.\text{°F}$$

Diketahui :

$$Q = 5011,0522 \text{ kJ/jam} \quad 4750,4775 \text{ Btu/jam}$$

$$\Delta T_{LMTD} = 121,4444 \text{ °F}$$

maka :

$$\begin{aligned} \text{Akebutuhan} &= Q / (UD \times \Delta T_{LMTD}) \\ &= 0,2063 \text{ ft}^2 \end{aligned}$$

$$\text{Akebutuhan} < \text{Atersedia} = 0,2063 \text{ ft}^2 < 446,7807 \text{ ft}^2$$

sehingga jaket pemanas bisa digunakan

#### F. Desain Jaket Pemanas

Reaksi yang berlangsung dalam reaktor bersifat endotermis, sehingga panas yang harus diserap dari reaktor agar tidak menyebabkan kenaikan suhu. Jaket/koil yang dialiri air pemanas digunakan untuk menjaga temperatur reaktor agar suhu konstan pada 75°C.

1. Menentukan jumlah steam :

$$\text{Massa steam} = Q / (H_v - H_f)$$

Dimana :

$$Q = 5011,052246 \text{ kJ/jam}$$

$$H_g = 2676,4 \text{ kJ/kg}$$

$$H_f = 419,1 \text{ kJ/kg}$$

$$\text{sehingga massa steam} = 2,2199 \text{ kg/jam} = 0,0006 \text{ kg/sekon}$$

2. Menghitung tinggi jaket :

$$\text{Tebal jaket} = 0,3125 \text{ in}$$

$$\text{Diameter dalam jaket (IDj)} = 81,7750 \text{ in}$$

$$\begin{aligned} \text{Diameter luar jaket (ODj)} &= \text{IDj} + (2 \cdot \text{Tebal jaket}) \\ &= 82,4000 \text{ in} \end{aligned}$$

$$\text{OD standard} = 102 \text{ in}$$

$$\text{Tinggi jaket} = \text{Tinggi cairan dalam shell}$$

$$\begin{aligned} \text{Tinggi jaket} &= 4,9127 \text{ m} \\ &= 193,4152 \text{ in} \end{aligned}$$

3. Menghitung tebal dinding jaket :

Diketahui :

$$P \text{ desain} = 25,5907 \text{ psig}$$

Brownell and young 1959 page 254. Eq.13.1

Untuk menghitung tebal jaket dibutuhkan data-data sebagai berikut :

Bahan Konstruksi = Allowable stress untuk Carbon steels SA 299

Allowable stress (f) = 18750 Psi

Pengelasan = Double welded butt joint

Faktor pengelasan (E) = 0,8000

Faktor korosi (C) = 0,1250 in

$r_i = D/2 = 40,8875$  in

maka :

$t_s = 0,1599$  in

Diambil standard  $t_s = 0,1875$  in

#### 4. Menghitung tebal bottom

Untuk menghitung tebal bottom dibutuhkan data-data sebagai berikut :

Bahan Konstruksi = Allowable stress untuk Carbon steels SA 299

Allowable stress (f) = 18750 Psi

Pengelasan = Double welded butt joint

Faktor pengelasan (E) = 80%

Faktor korosi (C) = 0,125 in

Diketahui :

$P_{desain} = 25,5907$  psig

$$W = 1,7397 \text{ in}$$

Maka :

$$th = 0,1857 \text{ in}$$

Diambil standard  $th = 0,25 \text{ in}$

#### 5. Volume jaket

$$\text{Volume jaket} = \pi/4 \cdot OD2 \cdot \text{tinggi jaket}$$

$$= 1579648,8866 \text{ in}^3$$

$$= 40123,0817 \text{ m}^3$$

$$= 914,1491 \text{ ft}^3$$

$$\text{Luas yang dilalui steam (A)} = (3,14/4) \cdot (D22 - D12)$$

$$= 2917,7291 \text{ in}^2$$

$$= 1,8819 \text{ m}^2$$

$$= 243,1441 \text{ ft}^2$$

#### 6. Menentukan kecepatan volumetrik steam :

$$Q_v = W_t / \rho_{air}$$

Dimana :

$Q_v$  = kecepatan volumetrik air ( $\text{m}^3/\text{jam}$ )

$W_t$  = kebutuhan steam ( $\text{kg}/\text{jam}$ )

$\rho_{air}$  = Densitas air ( $\text{kg}/\text{m}^3$ )

Maka :

Sehingga  $Q_v = 0,0022 \text{ m}^3/\text{jam}$

### G. Penentuan Manhole

Setiap vessel yang dalam operasinya melibatkan cairan ataupun yang di dalamnya terdapat alat lain seperti impeller, sebaiknya dilengkapi dengan manhole. Manhole sangat dibutuhkan dalam vessel tertutup untuk pemeriksaan, pembersihan kolom dan perbaikan. Direncanakan manhole di pasang pada kolom bagian atas reaktor dengan ukuran standard 20 in berdasarkan Rekomendasi API standard 12 C. (Brownell and young, Ap. F item 4) dengan spesifikasi :

Tebal shell = 0,3125 in

Tebal flange = 1,5 in

Jumlah = 1

Ukuran potongan :

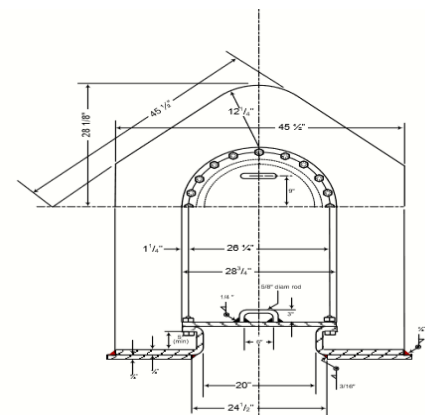
Weld A = 0,8750 in

Weld B = 1,5 in

Panjang sisi = 42,5 in

Lebar reinforcement (W) = 49,0 in

Diameter manhole (ID) = 20,0 in



Gambar F.11. Manhole



Maksimum diameter lubang ( $D_p$ ) = 27,0 in

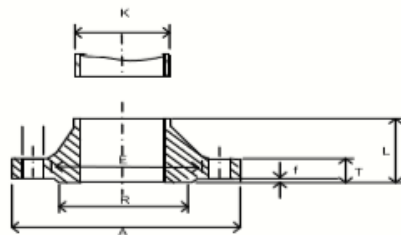
Diameter plat penutup :

Cover plate = 28,75 in

Diameter bolt circle (DB) = 25,25 in Manhole

## H. Perancangan Nozzle

Dipilih jenis pipa : Carbon stell



Gambar.F.10. Detail *nozzle*

### 1. Diameter saluran masuk umpan campuran

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

$$d, optimum = 293.G^{0,53} .\rho^{-0,37}$$

$d$  = diameter saluran umpan campuran

$G$  = kecepatan umpan masuk = 10004,9287 kg/jam = 2,7791 kg/s

$\rho$  = densitas campuran = 1026,7958 kg/m<sup>3</sup>

maka :

$d$  optimum = 38,7161 mm = 1,5243 in

$d$  optimum standart = 2 in

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

$$\text{NPS} = 2 \text{ in}$$

$$\text{Sch} = 40$$

$$\text{ID} = 2,067 \text{ in}$$

$$\text{OD} = 2,38 \text{ in}$$

$$A = 3,35 \text{ in}^2$$

Laju alir volumetrik (Fv) :

$$Fv = G/\rho_{\text{mix}}$$

$$= 9,7438 \text{ m}^3/\text{jam} = 0,00270662 \text{ m}^3/\text{s} = 165,1680 \text{ in}^3/\text{s}$$

Kecepatan aliran (v) :

$$v = Fv/A$$

$$= 49,3039 \text{ in/s} = 1,2523 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih

ukuran standart (Sch 40) :

$$\text{size of nozzle} = 2$$

$$\text{OD} = 2,875 \text{ in}$$

Flanged Nozzle = Coupling

$$\text{DR} = 3 \text{ in}$$

Distance from bottom of tank to center of nozzle :

$$\text{reguler, type H} = 7$$

low, type G = 3

## 2. Diameter saluran umpan gas

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

$$d, optimum = 293.G^{0.53}.\rho^{-0.37}$$

Keterangan :

d = diameter saluran umpan gas

G = kecepatan umpan masuk = 885,6768 kg/jam = 0,2460 kg/s

$\rho$  = densitas gas = 3,4802 kg/m<sup>3</sup>

maka :

d optimum = 87,8394 mm = 3,4582 in

d optimum standart = 4 in

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

NPS = 4 in

Sch = 40

ID = 4,026 in

OD = 4,5 in

A = 12,7 in<sup>2</sup>

Laju alir volumetrik (Fv) :

Fv = G/ $\rho$ gas

$$= 254,4898 \text{ m}^3/\text{jam} = 0,0707 \text{ m}^3/\text{s} = 4313,8641 \text{ in}^3/\text{s}$$

Kecepatan aliran (v) :

$$v = Fv/A$$
$$= 339,6743 \text{ in/s} = 8,6277 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih ukuran standart (Sch 40) :

size of nozzle = 4

OD = 4,5 in

Flanged Nozzle = 0,337

DR = 4,625 in

Distance from bottom of tank to center of nozzle :

reguler, type H = 9

low, type G = 6

### 3. Diameter saluran produk

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

$$d, optimum = 293.G^{0,53}.\rho^{-0,37}$$

Keterangan :

d = diameter saluran produk

G = kecepatan umpan masuk = 10004,9287 kg/jam = 2,7791 kg/s

$\rho$  = densitas mix = 1051,6619 kg/m<sup>3</sup>

Maka :

$$d_{\text{optimum}} = 38,3748 \text{ mm} = 1,5108 \text{ in}$$

$$d_{\text{optimum standart}} = 2 \text{ in}$$

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

$$\text{NPS} = 2 \text{ in}$$

$$\text{Sch} = 40$$

$$\text{ID} = 2,067 \text{ in}$$

$$\text{OD} = 2,38 \text{ in}$$

$$A = 3,35 \text{ in}^2$$

Laju alir volumetrik ( $F_v$ ) :

$$F_v = G/\rho_{\text{mix}}$$

$$= 9,5134 \text{ m}^3/\text{jam} = 0,0026 \text{ m}^3/\text{s} = 161,2627 \text{ in}^3/\text{s}$$

Kecepatan aliran ( $v$ ) :

$$v = F_v/A$$

$$= 48,1381 \text{ in/s} = 1,2227 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih

ukuran standart (Sch 40) :

$$\text{size of nozzle} = 2$$

$$\text{OD} = 2,875 \text{ in}$$

Flanged Nozzle = Coupling

$$\text{DR} = 3 \text{ in}$$

Distance from bottom of tank to center of nozzle :

regular, type H = 7

low, type G = 3

#### 4. Diameter saluran steam masuk

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

Keterangan :

d = diameter saluran steam input

G = kecepatan umpan masuk = 2,2199 kg/jam = 0,0006 kg/s

$\rho$  = densitas steam = 992,8500 kg/m<sup>3</sup>

Maka :

d optimum = 0,4537 mm = 0,0179 in

d optimum standart = 0,125 in

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

NPS = 0,125 in

Sch = 40

ID = 0,269 in

OD = 0,405 in

A = 0,058 in<sup>2</sup>

Laju alir volumetrik (Fv) :

$$F_v = G/\rho_{mix}$$

$$= 0,0022 \text{ m}^3/\text{jam} = 0,000001 \text{ m}^3/\text{s} = 0,0379 \text{ in}^3/\text{s}$$

Kecepatan aliran (v) :

$$v = F_v/A$$

$$= 0,6535 \text{ in/s} = 0,0166 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih ukuran standart (Sch 40) :

$$\text{size of nozzle} = 0,75$$

$$\text{OD} = 1,313 \text{ in}$$

Flanged Nozzle = Coupling

$$\text{DR} = 1,4375 \text{ in}$$

Distance from bottom of tank to center of nozzle :

reguler, type H = 4

low, type G = 3

#### 5. Diameter saluran steam keluar

Coulson and Richardson vol.6, 1983, P.221, Eq 5.15

$$d, optimum = 293 \cdot G^{0,53} \cdot \rho^{-0,37}$$

Keterangan :

d = diameter saluran steam output

G = kecepatan umpan masuk = 2,2199 kg/jam = 0,0006 kg/s

$$\rho = \text{densitas steam} = 992,8500 \text{ kg/m}^3$$

Maka :

$$d \text{ optimum} = 0,4537 \text{ mm} = 0,0179 \text{ in}$$

$$d \text{ optimum standart} = 0,125 \text{ in}$$

Spesifikasi pipa dari tabel 11, P.844, Kern, 1980

$$\text{NPS} = 0,125 \text{ in}$$

$$\text{Sch} = 40$$

$$\text{ID} = 0,269 \text{ in}$$

$$\text{OD} = 0,405 \text{ in}$$

$$A = 0,058 \text{ in}^2$$

Laju alir volumetrik ( $F_v$ ) :

$$F_v = G/\rho_{\text{mix}}$$

$$= 0,0022 \text{ m}^3/\text{jam} = 0,000001 \text{ m}^3/\text{s} = 0,0379 \text{ in}^3/\text{s}$$

Kecepatan aliran ( $v$ ) :

$$v = F_v/A$$

$$= 0,6535 \text{ in/s} = 0,0166 \text{ m/s}$$

Spesifikasi pipa dari (Brownel and Young, 1959, app F p.349), dipilih

ukuran standart (Sch 40) :

$$\text{size of nozzle} = 0,75$$



$$OD = 1,313 \text{ in}$$

Flanged Nozzle = Coupling

$$DR = 1,4375 \text{ in}$$

Distance from bottom of tank to center of nozzle :

regular, type H = 4

low, type G = 3

## I. Perancangan penyangga Reaktor

### 1. Berat shell

$$ID = 81,7750 \text{ in} = 6,8146 \text{ ft}$$

$$OD = 102 \text{ in} = 8,5000 \text{ ft}$$

$$H = 163,5500 \text{ in} = 13,6292 \text{ ft}$$

$\rho$  = densitas carbon stell (Foust, App. D-10, p.742)

$$= 489 \text{ lb/ft}^3 = 7833,0465 \text{ kg/m}^3$$

Maka :

$$\text{Berat shell} = \frac{1}{4}\pi(OD^2 - ID^2)H\rho$$

$$= 135039,4108 \text{ lb} = 61252,7964 \text{ kg}$$

### 2. Berat head

$$OD = 102 \text{ in} = 8,5000 \text{ ft}$$

$$sf = 1,5 \text{ in} = 0,1250 \text{ ft}$$

$$icr = 6,125 \text{ in} = 0,5104 \text{ ft}$$

$$th = 0,31 \text{ in} = 0,0260 \text{ ft}$$

$$\rho = 489,0000 \text{ lb/ft}^3 \quad (\text{Foust, App. D-10, p.742})$$

Untuk  $th < 1$  in perkiraan blank diameter (bd) adalah :

$$bd = OD + OD/42 + 2 \cdot sf + 2/3 \text{ icr} \quad (\text{Brown and young, Eq. 5-12, p.88})$$

$$= 111,512 \text{ in} = 9,293 \text{ ft}$$

$$\text{Berat dish} = 2(1/4\pi \cdot bd^2 \cdot th \cdot \rho_{\text{steel}})$$

$$= 1726,4630 \text{ lb} = 783,1098 \text{ kg}$$

### 3. Berat jaket

$$V_j = 914,1491 \text{ ft}^3$$

$$\rho = 489 \text{ lb/ft}^3$$

Maka :

$$\text{Berat jaket} = 447018,9242 \text{ lb}$$

$$= 202764,2079 \text{ kg}$$

### 4. Berat Opening

#### a. Berat nozzle 1

ukuran = 2 in Appendix. Untuk menentukan ukuran standard

berat = 4 lb

b. Berat nozzle 2

ukuran = 4 in

berat = 15 lb

c. Berat nozzle 3

ukuran = 2 in

berat = 4 lb

d. Berat nozzle 4

ukuran = 0,125 in

diambil, ukuran standart = 0,5 in

berat = 2 lb

e. Berat nozzle 5

ukuran = 0,125 in

diambil, ukuran standart = 0,5 in

berat = 2 lb

berat total nozzle = 27 lb = 12,2470 kg

f. Berat manhole

manhole 20 in = 428,00 lb (Megyesy, pp. 413)

Berat tutup = 29,22 lb (Megyesy, pp. 384)

$$\text{Berat manhole} = \text{Manhole 20 in} + \text{Berat tutup}$$

$$= 457,22 \text{ lb} = 207,39 \text{ kg}$$

$$\text{Berat total Opening} = \text{Berat total nozzle} + \text{Berat manhole}$$

$$= 484,2200 \text{ lb} = 219,6383 \text{ kg}$$

#### 5. Berat sistem pengaduk

##### a. Berat impeller

$$D_i = 0,6924 \text{ m} = 2,2715 \text{ ft}$$

$$W = 0,1647 \text{ m} = 0,5403 \text{ ft}$$

$$t_a = 0,1647 \text{ m} = 0,5403 \text{ ft}$$

$$\rho = 489 \text{ lb/ft}^3$$

Berat total six blade :

$$\text{Berat impeller} = 6 \left( \frac{D_i}{2} \right) \cdot W \cdot t_a \cdot \rho$$

$$= 972,6710 \text{ lb}$$

##### b. Berat sumbu

$$L = 4,5252 \text{ m} = 14,8464 \text{ ft}$$

$$d = 4,3852 \text{ cm} = 0,0439 \text{ m} = 0,1439 \text{ ft}$$

$$\rho = 489 \text{ lb/ft}^3$$

$$\text{Berat sumbu} = \frac{1}{4} \cdot \pi \cdot d^2 \cdot L \cdot \rho$$

$$= 117,9627 \text{ lb}$$

Berat total

Berat total = Berat impeller + berat sumbu

$$= 1090,6337 \text{ lb} = 494,7027 \text{ kg}$$

#### 6. Berat Baffle

Panjang Baffle (H) = 4,1947 m = 13,7622 ft

Lebar baffle (w) = 0,1177 m = 0,3862 ft

Tebal baffle (W) = 0,1647 m = 0,5403 ft

jumlah = 4 buah

$\rho = 489 \text{ lb/ft}^3$

Berat total baffle = jumlah x tebal x lebar x tinggi x  $\rho$

$$= 5616,0878 \text{ lb} = 2547,4125 \text{ kg}$$

#### 7. Berat fluida dalam reaktor

a. Berat bahan baku

Laju alir massa = 10004,9287 kg/jam

Waktu tinggal = 2,4366 jam

Berat bahan baku = laju alir massa x waktu tinggal

$$= 24377,9617 \text{ kg} = 53744,1420 \text{ lb}$$

b. Berat steam

$$\text{Volume jaket} = 914,1491 \text{ ft}^3$$

$$\rho \text{ steam} = 992,8500 \text{ lb/ft}^3$$

$$\text{Berat air pendingin} = V_j \times \rho \text{ air pendingin}$$

$$= 907612,9630 \text{ lb} = 411685,9791 \text{ kg}$$

Berat total fluida

$$\text{Berat total fluida} = \text{Berat bahan baku} + \text{Berat air pendingin}$$

$$= 961357,1050 \text{ lb} = 436063,8920 \text{ kg}$$

8. Berat reaktor

$$\begin{aligned} \text{Berat mati reaktor} &= \text{Berat shell} + \text{berat head} + \text{berat jaket} + \text{Berat} \\ &\text{opening} + \text{berat pengaduk} + \text{berat baffle} + \text{berat} \\ &\text{fluida dalam reaktor} \end{aligned}$$

$$= 1552332,8445 \text{ lb} = 704125,7596 \text{ kg}$$

Maka :

Desain sistem penyangga

$$\text{Berat untuk perancangan} = 1,2 \times \text{Berat mati reaktor}$$

$$= 1862799,4134 \text{ lb} = 844950,9115 \text{ kg}$$