LAMPIRAN A

PERHITUNGAN

REAKTOR

REAKTOR

Fungsi = Mereaksikan *o-xylene* dan udara menjadi *phthalic anhydride*

Tipe = Reaktor *fixed bed multitube*

Suhu = 350 ^oC

= 623 K

Tekanan = 6 atm

Katalis Rh-Si

Bentuk = *hollow cylindrical*

Diameter = 0,72 cm

Densitas = 0,99 gr/cm3 = 990 kg/m3

Umpan Masuk Reaktor

Komponen	**BM**	**Masuk**		**Keluar**	
		Kg/j	**Kmol/j**	**Kg/j**	**Kmol/j**
O_2	31,9988	69788,5976	2180,9755	66536,5306	2079,3446
N_2	28	16441,1996	587,1857	16441,1996	587,1857
CO	28	781,3484	27,9053	1260,3286	45,0117
CO_2	44	1,2303	0,0280	938,8399	21,3373
Ar	39,998	1,1184	0,0280	1,1184	0,0280
o-xylene	106	2606,5937	24,5905	1,3033	0,0123
m-xylene	106,16	627,1272	5,9074	627,1272	5,9074
$C_8H_4O_3$	148			2811,845688	18,9990
$C_8H_8O_2$	116			5,702145026	0,0492
$C_8H_6O_2$	134			6,586960633	0,0492
$C_7H_6O_2$	122			23,98833425	0,1966
$C_5H_6O_4$	130			3,195167471	0,0246
$C_4H_2O_3$	98			96,34658836	0,9831
H_2O	18			1493,126338	82,9515
Total		90247,2	2826,6	90247,2	2842,08

1. Menentukan Yi

Komponen	BM	Masuk		yi	yi.BM
		Kg/j	Kmol/j		
O_2	31,9988	69788,5976	2180,9755	0,7716	24,6898
N_2	28	16441,1996	587,1857	0,2077	5,8166
CO	28	781,3484	27,9053	0,0099	0,2764
CO_2	44	1,2303	0,0280	0,0000	0,0004
Ar	39,998	1,1184	0,0280	0,0000	0,0004
o-xylene	106	2606,5937	24,5905	0,0087	0,9222
m-xylene	106,16	627,1272	5,9074	0,0021	0,2219
$C_8H_4O_3$	148	0	0	0	0
H_2O	18	0	0	0	0
		90247,2152	2826,6203	1,0000	31,9276

2. Menentukan Z umpan masuk reaktor

Data untuk menentukan Z umpan

Komponen	BM	Yi	Pc (atm)	Tc (k)	w
O_2	31,9988	0,7695	50,43	154,58	0,22
N_2	28	0,2072	33,94	126,1	0,04
CO	28	0,0098	34,99	132,92	0,066
CO_2	44	0,0000	73,82	304,19	0,228
Ar	39,998	0,0000	48,98	150,96	0
o-xylene	106	0,0108	37,34	630,37	0,313
m-xylene	106,16	0,0026	35,41	617,05	0,326
$C_8H_4O_3$	148	0,0000	47,2	791	0,708
H_2O	18	0,0000	220,55	647,13	0,345
				3554,3	

Perhitungan nilai Yi.BM, Yi.Pc, Yi.Tc, Yi.w

Komponen	w	Yi.BM	Yi.Pc	Yi.Tc	Yi.w
O_2	0,22	24,6898	38,9110	119,2715	0,1697
N_2	0,04	5,8166	7,0505	26,1953	0,0083
CO	0,066	0,2764	0,3454	1,3122	0,0007
CO_2	0,228	0,0004	0,0007	0,0030	0,0000
Ar	0	0,0004	0,0005	0,0015	0,0000
o-xylene	0,313	0,9222	0,3248	5,4840	0,0027

Lanjutan Tabel Perhitungan Yi.BM, Yi.Pc, Yi.Tc, Yi.w

Komponen	**w**	**Yi.BM**	**Yi.Pc**	**Yi.Tc**	**Yi.w**
m-xylene	0,326	0,2219	0,0740	1,2896	0,0007
$C_8H_4O_3$	0,708	0,0000	0,0000	0,0000	0,0000
H_2O	0,345	0,0000	0,0000	0,0000	0,0000
Total		31,9276	46,7070	153,5570	

Tc umpan = 153,5570 K

Pc umpan = 46,7070 atm

Tr (T/Tc) = 4,0571

Pr (P/Pc) = 0,1285

Pr/Tr = 0,0317

Dari harga Tr = 2,8034 dan Pr = 0,6405 berdasarkan Fig. 3.15 (Smith van Ness), untuk menentukan Z menggunakan koefisien virial dengan menggunakan persamaan 3.61 sampai 3.66

$$B^{\cap} = \frac{BPc}{RTc} = B^{o} + \omega B^{1}$$

$$B^{o} = 0{,}083 - \frac{0.422}{Tr^{1.6}}$$

$$Z = 1 + \left(\frac{BPc}{RTc}\right)\left(\frac{Pr}{Tr}\right)$$

$$Z = 1 + \frac{BP}{RT} = 1 + B^{\cap}\frac{Pr}{Tr}$$

$$B^{1} = 0{,}139 - \frac{0.172}{Tr^{4.2}}$$

Perhitungan nilai Z

Komponen	**Yi**	**Tr**	**Pr**	**B_0**	**B_1**
O_2	0,7716	4,0303	0,1190	0,0376	0,1385
N_2	0,2077	4,9405	0,1768	0,0502	0,1388
CO	0,0099	4,6870	0,1715	0,0474	0,1387
CO_2	0,0000	2,0481	0,0813	-0,0510	0,1305
Ar	0,0000	4,1269	0,1225	0,0393	0,1386
o-xylene	0,0087	0,9883	0,1607	-0,3470	-0,0417
m-xylene	0,0021	1,0096	0,1694	-0,3326	-0,0262
$C_8H_4O_3$	0,0000	0,7876	0,1271	-0,5353	-0,3298
H_2O	0,0000	0,9627	0,0272	-0,3655	-0,0628
Total	1,0000				

Lanjutan Tabel Perhitungan Z

Komponen	BPc/RTc	Pr/Tr	Z	Yi.Z
O_2	0,0376	0,0295	1,0011	0,7724
N_2	0,0937	0,0358	1,0034	0,2084
CO	0,0926	0,0366	1,0034	0,0099
CO_2	0,0414	0,0397	1,0016	0,0000
Ar	0,0871	0,0297	1,0026	0,0000
o-xylene	-0,3470	0,1626	0,9436	0,0082
m-xylene	-0,3326	0,1678	0,9442	0,0020
$C_8H_4O_3$	-0,5353	0,1614	0,9136	0,0000
H_2O	-0,3655	0,0283	0,9897	0,0000
				1,00

Z umpan masuk reaktor = 1,00

BM campuran = 31,9276

3. Menentukan volume gas masuk reaktor

$$Vg = \frac{Z.n.R.T}{P}$$

Dimana :

Vg = Laju alir volumetrik,cm3/dtk

n = mol umpan,mol/dtk

R = Konstanta gas,cm3.atm/gmol.K

T = temperatur,K

P = Tekanan,atm

Z = 1,0010

n = 9,4278 mol/dtk

T = 0,027961224 K

P = 2606,593696 atm

Vg = 0,008306077 cm^3/dtk

= 0,0000 m^3/dtk

R = 82,05 cm^3.atm/gmol.K

4. Menentukan densitas umpan

$$\rho = \frac{P.BM}{R.T.Z}$$

p = 0,0037439 gr/cm^3 = 235,7842 lb/ft^3

5. Menentukan viskositas umpan

T = 0,027961224 K

T_2 = 0,00078183 K

Data viskositas gas

Komponen	**A**	**B**	**C**
O_2	29,526	-8,90E-03	3,81E-05
N_2	29,342	-3,54E-03	1,01E-05
CO	29,556	-6,58E-03	2,01E-05
CO_2	27,437	4,23E-02	-1,96E-05
Ar	20,786	0,00E+00	0,00E+00
o-xylene	0,182	5,13E-01	-2,02E-04
m-xylene	-16,725	5,64E-01	-2,65E-04
$C_8H_4O_3$	40,083	3,61E-02	9,60E-04
H_2O	33,933	-8,42E-03	2,99E-05

$$\eta_{gas} = A + BT + CT^2$$

Hasil perhitungan viskositas gas

Komponen	**yi**	**η gas (mikropoise)**	**μ_{gas} (kg/s.m)**	**μ_{gas} (kg/jam.m)**	**μ_{gas} lb/ft.jam**
O_2	0,7716	29,525751	0,000003	0,010629	0,000003
N_2	0,2077	29,341901	0,000003	0,010563	0,000003
CO	0,0099	29,555816	0,000003	0,010640	0,000003
CO_2	0,0000	27,438183	0,000003	0,009878	0,000002
Ar	0,0000	20,786000	0,000002	0,007483	0,000002
o-xylene	0,0087	0,196356	0,000000	0,000071	0,000000
m-xylene	0,0021	-16,709223	-0,000002	-0,006015	-0,000001
$C_8H_4O_3$	0	40,084010	0,000004	0,014430	0,000003

Lanjutan Tabel hasil perhitungan viskositas gas

Komponen	**yi**	**η gas**	**μ_{gas}**	**μ_{gas}**	**μ_{gas}**
		(mikropoise)	**(kg/s.m)**	**(kg/jam.m)**	**lb/ft.jam**
H_2O	0	33,932765	0,000003	0,012216	0,000003
	1,0000	194,1516	0,0000	0,0699	0,0000

Lanjutan perhitungan viskositas gas

Komponen	**yi.μ_{gas}**	**yi.μ_{gas}**	**yi.μ_{gas}**	**η gas**
	(kg/s.m)	**(kg/jam.m)**	**lb/ft.jam**	**mikropoise**
O_2	0,000002278160	0,008201	0,00000198473	22,781602
N_2	0,000000609532	0,002194	0,00000053102	6,095316
CO	0,000000029178	0,000105	0,00000002542	0,291784
CO_2	0,000000000027	0,000000	0,00000000002	0,000271
Ar	0,000000000021	0,000000	0,00000000002	0,000206
o-xylene	0,000000000171	0,000001	0,00000000015	0,001708
m-xylene	-0,000000003492	-0,000013	-0,00000000304	-0,034921
$C_8H_4O_3$	0,000000000000	0,000000	0,00000000000	0,000000
H_2O	0,000000000000	0,000000	0,00000000000	0,000000
	0,000002913597	0,010488948346	0,000002538325	29,135967626743

μgas = 0,00000291 kg/s.m

0,00002914 gr/cm.s

6. Menghitung konduktivitas umpan

(Chemical properties handbook,Mc Graw-hill Carl L.Yaws)

$k_{gas} = A + BT + CT_2$

T = 623 K

T_2 = 388129 K

Data konduktivitas (Chemical properties handbook,Mc Graw-hill Carl L.Yaws)

Komponen	**A**	**B**	**C**
O_2	0,00121	8,62E-05	-1,33E-08
N_2	0,00309	7,59E-05	-1,10E-08
CO	0,0015	8,27E-05	-1,92E-08

Lanjutan Tabel Data konduktivitas

Komponen	A	B	C
CO_2	0,01183	1,02E-04	-2,22E-08
Ar	0,00548	4,39E-05	-6,81E-05
o-xylene	-0,00979	7,41E-05	1,84E-08
m-xylene	-0,00375	3,00E-05	7,46E-08
$C_8H_4O_3$	-0,00753	3,82E-05	1,55E-08
H_2O	0,00053	4,71E-05	4,96E-08

Hasil perhitungan konduktivitas umpan

Komponen	yi	k_{gas}	$yi.k_{gas}$
		W/m.K	W/m.K
O_2	0,7716	0,0497	0,0384
N_2	0,2077	0,0461	0,0096
CO	0,0099	0,0456	0,0005
CO_2	0,0000	0,0666	0,0000
Ar	0,0000	-26,4147	-0,0003
o-xylene	0,0087	0,0435	0,0004
m-xylene	0,0021	0,0439	0,0001
$C_8H_4O_3$	0	0,0223	0,0000
H_2O	0	0,0491	0,0000
Total	1,0000	-26,0479	0,0486

k campuran = 0,0486 W/m.K (1kj = 0,238846 kkal)

= 0,1749 kJ/jam.m.K

= 0,0418 kkal/jam.m.K

= 0,0001 kal/dtk.cm.K

7. Menentukan kapasitas panas gas umpan

$Cp = A + BT + CT^2 + DT^3 + ET^4$

T ref = 25 C = 298 K T^2 = 388129 K

T = 623 K T^3 = 241804367 K

T^4 = 1,50644E+11 K

Data kapasitas panas gas umpan (Chemical properties handbook,Mc Graw-hill Carl L.Yaws)

Komponen	A	B	C	D	E
O_2	29,526	-8,90E-03	3,81E-05	-3,26E-08	8,86E-12
N_2	29,342	-3,54E-03	1,01E-05	-4,31E-09	2,59E-13
CO	29,556	-6,58E-03	2,01E-05	-1,22E-08	2,26E-12
CO_2	27,437	4,23E-02	-1,96E-05	4,00E-09	-2,99E-13
Ar	20,786	0,00E+00	0,00E+00	0,00E+00	0,00E+00
o-xylene	0,182	5,13E-01	-2,02E-04	-2,16E-08	2,32E-11
m-xylene	-16,725	5,64E-01	-2,65E-04	1,3381E-08	1,59E-11
$C_8H_4O_3$	40,083	3,61E-02	9,60E-04	-1,78E-08	3,69E-12
H_2O	33,933	-8,42E-03	2,99E-05	-1,23E-06	4,66E-10

Menghitung nilai Cp campuran bagian 1

Komponen	yi	BM	Cp	Cp	Cp	Cpi = yi.Cp
		(kg/kmol)	(joule/mol.K)	kjoule/kmol.K	kjoule/kg.K	kjoule/kg.K
O_2	0,7716	31,9988	32,2075	32,2075	1,0065	0,7766
N_2	0,2077	28	30,0442	30,0442	1,0730	0,2229
CO	0,0099	28	30,6534	30,6534	1,0948	0,0108
CO_2	0,0000	44	47,1308	47,1308	1,0712	0,0000
Ar	0,0000	39,998	20,7860	20,7860	0,5197	0,0000
o-xylene	0,0087	106	239,8766	239,8766	2,2630	0,0197
m-xylene	0,0021	106,16	237,7043	237,7043	2,2391	0,0047
$C_8H_4O_3$	0,0000	148	431,2426	431,2426	2,9138	0,0000
H_2O	0,0000	18	-188,0187	-188,0187	-10,4455	0,0000
Total	1,0000	550,1568	881,6268	881,6268	1,7355	1,0347

Perhitungan nilai cp campuran bagian 2

Komponen	Fi	Fi.Cpi	Cp.yi
	(kg/jam)	Kjoule/jam.K	Kjoule/kmol.K
O_2	69788,5976	5,42E+04	2,49E+01
N_2	16441,1996	3,66E+03	6,24E+00
CO	781,3484	8,44E+00	3,03E-01
CO_2	1,2303	1,30E-05	4,66E-04
Ar	1,1184	5,75E-06	2,06E-04

Lanjutan perhitungan nilai cp campuran bagian 2

Komponen	Fi	Fi.Cpi	Cp.yi
	(kg/jam)	**Kjoule/jam.K**	**Kjoule/kmol.K**
o-xylene	2606,5937	5,13E+01	2,09E+00
m-xylene	627,1272	2,93E+00	4,97E-01
$C_8H_4O_3$	0,0000	0,00E+00	0,00E+00
H_2O	0,0000	0,00E+00	0,00E+00
Total	90247,2152	57926,3479	33,9789

Cp campuran = 33,978 kjoule/kmol.K

= 57926,3479 kjoule/jam.K

= 1,0347 kjoule/kg.K

(Chemical properties handbook,Mc Graw-hill Carl L.yaws)

T umpan = 623 K

T ref = 298 K

Data Kapasitas Panas gas masing masing komponen

Komponen	A	B	C	D	E
O_2	29,526	-8,90E-03	3,81E-05	-3,26E-08	8,86E-12
N_2	29,342	-3,54E-03	1,01E-05	-4,31E-09	2,59E-13
CO	29,556	-6,58E-03	2,01E-05	-1,22E-08	2,26E-12
CO_2	27,437	4,23E-02	-1,96E-05	4,00E-09	-2,99E-13
Ar	20,786	0,00E+00	0,00E+00	0,00E+00	0,00E+00
o-xylene	0,182	5,13E-01	-2,02E-04	-2,16E-08	2,32E-11
m-xylene	-16,725	5,64E-01	-2,65E-04	1,3381E-08	1,59E-11
$C_8H_4O_3$	40,083	3,61E-02	9,60E-04	-1,78E-08	3,69E-12
H_2O	33,933	-8,42E-03	2,99E-05	-1,23E-06	4,66E-10

Hasil perhitungan kapasitas panas gas masing masing komponen

Komponen	ΔHf (kj/mol)	ΔHf (kJ/kmol)	ΔH(J/mol)	ΔH(kJ/kmol)
O_2	0	0	9995,2168	9995,2168
N_2	0	0	9580,5448	9580,5448
CO	-110,5	-110500	9670,7668	9670,7668
CO_2	-393,5	-393500	13983,5079	13983,5079
Ar	0	0	6755,4500	6755,4500

Lanjutan Tabel hasil perhitungan kapasitas panas gas masing-masing komponen

Komponen	**ΔHf (kj/mol)**	**ΔHf (kJ/kmol)**	**ΔH(J/mol)**	**ΔH(kJ/kmol)**
o-xylene	19	19000	62046,9950	62046,9950
m-xylene	17,24	17240	60781,2663	60781,2663
$C_8H_4O_3$	-393,13	-393130	86736,2862	86736,2862
H_2O	-136,3	-136300	-23616,7346	-23616,7346

$C_8H_{10} + 3O_2 \rightarrow C_8H_4O_3 + 3H_2O$

(1 KJ/kcal = 0,238846 kcal/kmol)

ΔHR 298 = ΔHf produk - ΔHf reaktan

= -548430 Kj/kmol

ΔHr = 72042,2118 Kj/kmol

ΔHp = 110353,0209 Kj/kmol

ΔHR = -510119,1910 Kj/kmol

= -121839,9283 kkal/kmol

Reaksi Eksotermis

ΔHR 298 = ΔHf produk - ΔHf reaktan

= 393500 Kj/kmol

ΔHr = 23978,7247 Kj/kmol

ΔHp = 6755,4500 Kj/kmol

ΔHR = 424234,1747 Kj/kmol

= 101326,6357 kkal/kmol

8. Katalisator

Katalis = Rh-Si

Bentuk = *hollow cylindrical*

Diameter = 0,72 cm

Diameter Dalam = 0,36 cm

Densitas = 0,99 gr/cm3 = 990 kg/m3

Porositas = 0,4

9. Menentukan ukuran *tube*

Diameter reaktor dipilih berdasarkan pertimbangan agar perpindahan panas berjalan dengan baik. Pengaruh rasio Dp/Dt terhadap koefisien perpindahan dalam pipa yang berisi butir-butir katalisator di bandingkan dengan pipa kosong (hw/h) telah diteliti oleh Colburn's, yaitu:

Dp/Dt	0,05	0,10	0,15	0,20	0,25	0,30
hw/h	5,50	7,00	7,80	7,50	7,00	6,60

(*Smith, Chem Kinetik Eng, P.571*)

dipilih Dp/Dt = 0,15 karena menghasilkan perpindahan panas yang paling besar

dimana :

hw :koefisien perpindahan panas dalam pipa berisi katalis

h :koefisien perpindahan panas dalam pipa kosong

Dp :diameter katalisator

Dt :diameter *tube*

Jenis : Rh-Si

Ukuran D : 0,72 cm D = 0,36 m

L : 0,7

density : 0,990 gr/cm^3

bulk density: 0,553 gr/cm^3

Bila dinyatakan dalam diameter bola secara ekiuvalen yang mempunyai volume yang sama dengan silinder (partikel), maka :

Vs = ((1/4πD^{2}L)-(1/4πD^{2}L)

Dp = 0,72 cm

Dp/Dt = 0,15

Dt = 4,80 cm = 1,890 in

Dari hasil perhitungan, maka dipilih ukuran pipa standar :

Ukuran pipa (IPS)	: 2,00 in	= 5,08 cm	= 0,0508 m
OD	: 2,38 in	= 6,0452 cm	= 0,0605 m
ID	: 2,067 in	= 5,2502 cm	= 0 ,0525 m
Flow area per pipe	: 3,350 in^2	= 21,6129 cm^2	= 0,0022 m
Schedule number	: 40		
Surface per lin ft	: 0,622 ft^2/ft		

(Kern, hal 8.44)

Aliran dalam pipa adalah aliran transisi, maka Nre = 2500

$NRe = \frac{Gt.Dt}{\mu}$ $Gt = \frac{\mu.NRe}{Dt}$ Gt : kecepatan massa per satuan luas

Nre = 2500

μ = 0,000029 g/cm/dtk

Dt = 5,2502 cm

G (umpan total) = 90247,25212 kg/jam

= 25068,6709 gr/dtk

Gt = 0,0139 gr/cm^2.dtk = 499,4566 kg/m^2.jam

At : Luas penampang total

$At = \frac{G}{Gt}$ = 1806908,0285 cm^2 = 180,6908 m^2

Ao : Luas penampang pipa

$Ao = \frac{\pi}{4} ID^2$ = 21,6380 cm^2 = 0,00216 m^2

Nt (jumlah pipa) max :

$Nt\ max = \frac{At}{Ao}$ = 83506,0621 buah

ρs = 0,9900 g/cm3

P = 6,0 atm

BM = 31,9276 g/gmol

R = 82,05 cm^3.atm/gmol K

T udara = 303 K

ρg = 0,0037439 g/cm^3

ρ udara = $\frac{P_{udara}.BM_{udara}}{R.T_{udara}}$ = 0,0077054 g/cm^3

Katalis Rh-Si

bentuk = *hollow*

Re = 2500

Fd = 0,4 (fig.69 Brown P.76)

$$V\ max = \sqrt{\frac{4(\rho_b - \rho_g)g.Dp}{3.\rho_g.f_D}}$$ = 587,7122 cm/detik
= 21157,6378 m/jam

$$Q = \frac{G}{\rho_g}$$ = 6695847,1956 cm3/s

$$At = \frac{Q}{Vmax}$$ = 11393,0724 cm^2

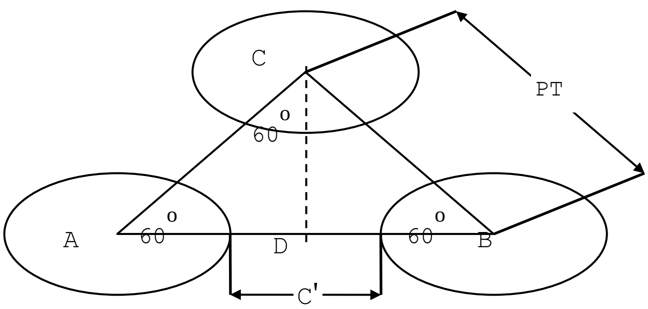
$$Nt\ min = \frac{At}{Ao}$$ = 526,5296 buah

Jadi, jumlah *tube* antara 526,5296 sampai 83506,0621

Dia ambil Nt 2100 buah

10. Menentukan diameter Reaktor (IDs)

pipa (tube) disusun dengan pola 'triangular pitch' agar turbulensi yang terjadi pada aliran fluida dalam shell menjadi besar, sehingga akan memperbesar koefisien perpindahan panas konveksi (ho)



Susunan *tube* = *triangular*

Pitch (PT) = 1,25 x ODt = 2,975 in = 7,5565 cm

Clearance (C") = PT – ODt = 0,5950 in = 1,5113 cm

untuk menghitung diameter *shell*, dicari luas penampang *shell* total (A total)

Luas *shell* = Luas segitiga

$$A\ total = 2.Nt.Luas\ segitiga\ ABC$$

$$\frac{\pi}{4} x IDs^2 = 2.Nt.\left(\frac{1}{2}.PT^2.sin60\right)$$

$$\frac{\pi}{4} x IDs^2 = 2.Nt.\left(\frac{1}{2}.PT^2.0,866\right)$$

Jadi : $IDs = \sqrt{\frac{4 \cdot Nt \cdot P_T^2 \cdot 0.866}{\pi}}$

= 363,7093 cm

= 143,1927 in

11. Menentukan Cp pendingin

Jenis = *Dow therm* A

T = 200 - 750 F (366.3 - 671.89 K)

BM = 165

Cp = 0.1152 + 0.0003402 T.cal/gr.K

Densitas (ρ) = 1.3644 - 9.7073.10^-4 T.g/cm3

Viskositas (μ) = 35.5898 - 6.04212 T(g/cm.J)

Kond. thermal (k) = 1.512 - 0.0010387 T.cal/g.cm.K

Pendingin *dowtherm*

	K	C	F
T in	298	25	77,0
T out	623	350	662,0
ΔT	325	325	585,0

1 cal = 4,186 Joule

1 Btu = 252 cal

1 lb = 454 gr

Cpp = 0,11152 + 0,0003402T

= 0,2129 Cal/gr K

= 0,3836 BTU/lb K

= 0,0008 BTU/gr K

= 0,8912 J/gr K

12. Menghitung densitas pendingin pada T in

$$\rho\ p = 1.3644 - (9.7073 x 10^{-4}\ Tin)$$

rho p = 1,0771 gr/cm^3

13. Menghitung konduktivitas thermal pendingin pada T in

Kp = 1,2025 cal/cm jam K

= 0,5034 kJ/m.jam.K

= 1,2408 Btu/ft.jam.F

14. Menghitung viskositas pendingin pada T in

μp = 23,0380 gr/cm jam

= 0,0064 gr/cm det

= 2,3038 kg/m.jam

= 1,5481 lb/ft.jam

15. Menentukan pendingin yang di butuhkan

Pendingin yang dipakai adalah *dow therm* A :

suhu steam masuk	= 25 C	= 298 K
suhu steam keluar	= 350 C	= 623 K
Cp *downtherm*	= 0,2129 Cal/gr.K	
Qh	= -2996105,557 kcal/jam	
	= -2996105557 kal/jam	

Pendingin yang dibutuhkan (Wp) = 43301097,47 gr/jam

= 43301,0975 kg/jam

= 12,0281 kg/sekon

16. Menghitung koefisien perpindahan panas *overall* (Ud)

a. *Tube side*

Cp = 33,9789 kj/kmol K

= 1,0347 kj/kg.K

= 0,24714 Btu/lb.F

μ = 0,00003 g/cm s

= 0,00705 lb/ft.h

k = 0,0486 W/m k

$= 0{,}02808$ Btu/ft.h.F

$$PR = \frac{Cp.\mu}{k} \quad = 0{,}0620$$

Gt = 0,01387 g/cm^2.dtk

Dt = 4,8 cm

Re = $\frac{G_T \ Dt}{\mu}$ = 2285,635921 → dari fig.24 Kern, P.834 didapat **jH = 8**

hi = $jH.\left(\frac{k}{IDt}\right).(Pr)^{1/3}$ = 0,3185 Btu/jam.ft^2.F

hio = hi x (ID/OD)

= 0,2766 Btu/jam.ft^2.F

b. *Shell side*

Didalam shell digunakan pendingin, dengan spesifikasi sbb :

sifat fisis pendingin → liquid

T = 298 K

µs = 23,0380 gr/cm.jam

= 0,00640 gr/cm.det

= 1,5481 lb/ft.jam

Cps :

T = 298 K

CPs = 0,2129 Cal/gr.K

= 98,1646 Btu/lb.F

= 0,8912 J/gr.K

Ks :

T = 298 K

Ks = 1,2408 Btu/ft.jam.F

Menghitung bilangan Reynold di *shell* (Res)

IDs = diameter dalam shell = 143,1927 in

B = *baffle spacing* = 35,7982 in (Kern,1965)

PT = *pitch tube* = 2,98 in

C' = jarak antar tube (*clearance*) = 0,5950 in

Ws = laju aliran pendingin = 43301,0975 kg/jam =

= 95462,4655 lb/jam

as = *flow area* pada *shell* (ft^2)

$$a_s = \frac{IDs.C'.B}{144.PT}$$ = 7,11949161 in^2

= 0,049440518 ft^2

Gs = *mass velocity* fluida dalam *shell*, $lb/ft^2.h$

$$Gs = \frac{Ws}{a_s}$$ = 1930854,8649 $lb/ft^2.h$

Diameter Equivalent (De)............ (Kern, 1983 P.139)

$$De = \frac{4\left(0,5.PT^2.0,866 - 0,5.\pi.\frac{OD^2}{4}\right)}{0,5.\pi.OD}$$

= 1,7225 in = 0,1435 ft = 4,375 cm

$$Re_s = \frac{Gs.De}{\mu_s}$$

= 179022,6550 → dari fig.28 Kern, P.838 didapat 320

$$h_o = jH\left(\frac{Ks}{De}\right)\left(\frac{Cp_s.\mu_s}{k_s}\right)^{1/3}$$

= 13737,8524 Btu/jam.ft^2.F

c. *Clean overall coefficient* (Uc)

$$Uc = \frac{h_{io}.h_o}{h_{io} + h_o}$$ = 0,2766 Btu/jam.ft^2.F

17. Menentukan Rd (*Dirty Factor*)

(Kern, halaman 107)

Dari tabel di dapat :

Rd *shell* : 0,0015

Rd *tube* : 0,001

Rd : Rd *shell* + Rd *tube*

: 0,0025

$$Ud = \frac{1}{Rd + \frac{1}{Uc}}$$

= 0,2764 Btu/jam.ft^2.F

= 1,3496 kkal/jam.m^2.K

= 5,6504 kj/jam.m^2.K

18. Menghitung panjang reaktor

Persamaan yang digunakan :

$$\frac{dX}{dZ} = \frac{(-rA).Nt.\pi.(IDt)^2}{4.FAo}$$ dimana $$-r_A = k.\left[\frac{\frac{F_{AO}.(1-x).P}{F_{TO}}}{R.T}\right]^2$$

Persamaan neraca panas pada elemen volume

$$\frac{dT}{dZ} = \frac{(-\Delta H_R).FAo.\frac{dX}{dZ} - Ud.\pi.ODt.Nt.(T - Tp)}{\sum Fi.Cpi}$$

dimana $\Delta HR = \Delta HR_{298} + \int_{298}^{T} \Delta Cp.dT$

Persamaan neraca panas pendingin

$$\frac{dTs}{dZ} = \frac{Ud.\pi.ODt.Nt.(T - Ts)}{Wp.Cp_p}$$

$$\sum Fi.Cpi = [F_{AO}.(1-x).C_{PA}] + \left[\left(F_{BO} + \frac{1}{2}.F_{AO}.x\right).(C_{PB})\right] + \left[\left(F_{CO} + \frac{1}{2}.F_{AO}.x\right).(C_{PC})\right] + \left[\left(F_{DO} + \frac{1}{2}.F_{AO}.x\right).(C_{PD})\right]$$

Persamaan di atas diselesaikan dengan cara euler

Data kapasitas panas gas masing masing komponen

Komponen	**A**	**B**	**C**	**D**	**E**
O_2	29,526	-8,90E-03	3,81E-05	-3,26E-08	8,86E-12
N_2	29,342	-3,54E-03	1,01E-05	-4,31E-09	2,59E-13
CO	29,556	-6,58E-03	2,01E-05	-1,22E-08	2,26E-12
CO_2	27,437	4,23E-02	-1,96E-05	4,00E-09	-2,99E-13
Ar	20,786	0,00E+00	0,00E+00	0,00E+00	0,00E+00
o-xylene	0,182	5,13E-01	-2,02E-04	-2,16E-08	2,32E-11
m-xylene	-16,725	5,64E-01	-2,65E-04	1,3381E-08	1,59E-11
$C_8H_4O_3$	40,083	3,61E-02	9,60E-04	-1,78E-08	3,69E-12
H_2O	33,933	-8,42E-03	2,99E-05	-1,23E-06	4,66E-10

Kondisi masuk reaktor :

konversi awal (Xo) = 0

posisi awal katalis (Zo) = 0

suhu masuk pipa (To) = 623 K

tekanan masuk pipa (Po) = 6,0 atm

aliran massa o-xylene masuk pipa (FAo) = 24,5905 kmol/jam

aliran massa masuk pipa total (FTo) = 2826,6203 kmol/jam

suhu pendingin masuk shell (Ts) = 298 K

aliran massa pendingin masuk shell (Ws) = 43301,0975 kg/jam

Diameter dalam tube (IDt) = 0,052502 m

Diameter luar tube (ODt) = 0,060452 m

Jumlah tube (Nt) = 2100 buah

Koef. perpindahan panas overall (Ud) = 5,6504 kJ/jam.m^2.K

Diameter katalis (Dp) = 0,0072 m

Porositas katalis dalam tube (ε) = 0,40

panas pembentukan standar (ΔH298) = -548430 kj/kmol

konstanta kecepatan reaksi (ko) = 1,000000E+00 m^3/kmol.jam

Energi aktivasi (Ea) = 800,4448 kJ/kmol

Kecepatan massa per satuan luas (Gt) = 499,4566 kg/m^2.jam

Konstanta gravitasi (g) = 12713760000 m/jam^2

cp s = -2996105,5572kal/gr.K

Rg = 1,987 kal/mol.K

R = 0,082057 atm.m^3/kmol.K

KT = 35051.5669 * EXP(-8004.4476 / T)

= 55,54764167

Ra = a(H_2) + b(CO) + c(C_2H_4)

= 0,16853236

Perhitungan nilai Mol.Yi

Komponen	**Mol**	**yi**	**A**	**B**	**C**
	(kmol/jam)				
O_2	2180,9755	0,7716	29,526	-8,90E-03	3,81E-05
N_2	587,1857	0,2077	29,342	-3,54E-03	1,01E-05
CO	27,9053	0,0099	29,556	-6,58E-03	2,01E-05
CO_2	0,0280	0,0000	27,437	4,23E-02	-1,96E-05
Ar	0,0280	0,0000	20,786	0,00E+00	0,00E+00
o-xylene	24,5905	0,0087	0,182	5,13E-01	-2,02E-04
m-xylene	5,9074	0,0021	-16,725	5,64E-01	-2,65E-04
		1,0000	22,5164286	0,076676	-2,191E-05

Lanjutan Tabel Perhitungan nilai Mol.Yi

Komponen	**D**	**E**	**Mol.Yi**
O_2	-3,26E-08	8,86E-12	1682,806145
N_2	-4,31E-09	2,59E-13	121,9785519
CO	-1,22E-08	2,26E-12	0,275490081
CO_2	4,00E-09	-2,99E-13	2,76595E-07
Ar	0,00E+00	0,00E+00	2,76595E-07
o-xylene	-2,16E-08	2,32E-11	0,213927927
m-xylene	1,3381E-08	1,59E-11	0,012345879
	-9,54083E-09	4,899E-12	

Tabel Iterasi Bagian 1

Δz	0,1000												
z (m)	**x**	**T (K)**	**Ts (K)**	**∫ ΔCP.dT (j/mol)**	**(-ΔHR)**	**P (atm)**	**ra, Kmol/ m3 jam**	**dx/dz**	**dT/dz**	**dTs/dz**	**dP/dz**	**Fi.Cpi**
0	0	623,0000	298	16969,70448	531460,2955	6,0	0,000428	0,0000791	0,0001	425,0781	0,0000000137114200	8885987,91835
0,10	0,07909	623,0000	340,5078	16969,70516	531460,2948	6,0	0,000394	0,0000728	0,0001	345,9801	0,0000000141749550	9254061,46176
0,20	0,15193	623,0000	375,1058	16969,70577	531460,2942	6,0	0,000363	0,0000671	0,0001	288,6627	0,0000000141749552	9598455,31864
0,30	0,21901	623,0000	403,9721	16969,70631	531460,2937	6,0	0,000334	0,0000618	0,0001	244,9883	0,0000000141749554	9915610,22648
0,40	0,28078	623,0000	428,4709	16969,70680	531460,2932	6,0	0,000308	0,0000569	0,0001	210,5373	0,0000000141749556	10207680,57997
0,50	0,33766	623,0000	449,5247	16969,70723	531460,2928	6,0	0,000283	0,0000524	0,0001	182,6658	0,0000000141749558	10476650,37752
0,60	0,39005	623,0001	467,7912	16969,70762	531460,2924	6,0	0,000261	0,0000482	0,0001	159,6792	0,0000000141749560	10724346,69831
0,70	0,43829	623,0001	483,7592	16969,70797	531460,2920	6,0	0,000240	0,0000444	0,0001	140,4329	0,0000000141749561	10952452,11337
0,80	0,48272	623,0001	497,8024	16969,70828	531460,2917	6,0	0,000221	0,0000409	0,0000	124,1216	0,0000000141749562	11162516,11514
0,90	0,52363	623,0001	510,2146	16969,70857	531460,2914	6,0	0,000204	0,0000377	0,0000	110,1600	0,0000000141749563	11355965,64293
1,00	0,56131	623,0001	521,2306	16969,70882	531460,2912	6,0	0,000188	0,0000347	0,0000	98,1107	0,0000000141749564	11534114,77595
1,10	0,59600	623,0001	531,0417	16969,70906	531460,2909	6,0	0,000173	0,0000320	0,0000	87,6396	0,0000000141749565	11698173,65968
1,20	0,62796	623,0001	539,8056	16969,70927	531460,2907	6,0	0,000159	0,0000294	0,0000	78,4864	0,0000000141749566	11849256,72628
1,30	0,65738	623,0001	547,6543	16969,70946	531460,2905	6,0	0,000147	0,0000271	0,0000	70,4446	0,0000000141749567	11988390,26473
1,40	0,68448	623,0001	554,6987	16969,70964	531460,2904	6,0	0,000135	0,0000250	0,0000	63,3487	0,0000000141749568	12116519,39235
1,50	0,70944	623,0001	561,0336	16969,70980	531460,2902	6,0	0,000124	0,0000230	0,0000	57,0636	0,0000000141749568	12234514,47479
1,60	0,73242	623,0001	566,7400	16969,70994	531460,2901	6,0	0,000115	0,0000212	0,0000	51,4782	0,0000000141749569	12343177,03840
1,70	0,75358	623,0001	571,8878	16969,71008	531460,2899	6,0	0,000105	0,0000195	0,0000	46,5003	0,0000000141749569	12443245,21484
1,80	0,77307	623,0001	576,5378	16969,71020	531460,2898	6,0	0,000097	0,0000179	0,0000	42,0525	0,0000000141749570	12535398,75514
1,90	0,79102	623,0001	580,7431	16969,71031	531460,2897	6,0	0,000089	0,0000165	0,0000	38,0694	0,0000000141749570	12620263,64717
2,00	0,80755	623,0001	584,5500	16969,71041	531460,2896	6,0	0,000082	0,0000152	0,0000	34,4952	0,0000000141749571	12698416,36789
2,10	0,82277	623,0001	587,9995	16969,71051	531460,2895	6,0	0,000076	0,0000140	0,0000	31,2822	0,0000000141749571	12770387,79930
2,20	0,83679	623,0001	591,1277	16969,71059	531460,2894	6,0	0,000070	0,0000129	0,0000	28,3893	0,0000000141749571	12836666,83464
2,30	0,84970	623,0001	593,9667	16969,71067	531460,2893	6,0	0,000064	0,0000119	0,0000	25,7810	0,0000000141749572	12897703,69940
2,40	0,86158	623,0001	596,5448	16969,71074	531460,2893	6,0	0,000059	0,0000109	0,0000	23,4262	0,0000000141749572	12953913,00963
2,50	0,87253	623,0001	598,8874	16969,71081	531460,2892	6,0	0,000055	0,0000101	0,0000	21,2978	0,0000000141749572	13005676,58840
2,60	0,88261	623,0001	601,0172	16969,71087	531460,2891	6,0	0,000050	0,0000093	0,0000	19,3721	0,0000000141749572	13053346,05944
2,70	0,89190	623,0001	602,9544	16969,71092	531460,2891	6,0	0,000046	0,0000086	0,0000	17,6282	0,0000000141749572	13097245,23572

Tabel Iterasi Bagian 2

z (m)	x	T (K)	Ts (K)	∫ ΔCP.dT (j/mol)	(-ΔHR)	P (atm)	ra, Kmol/ m3 jam	dx/dz	dT/dz	dTs/dz	dP/dz	Fi.Cpi
2,80	0,90045	623,0001	604,7172	16969,71097	531460,2890	6,0	0,000043	0,0000079	0,0000	16,0476	0,0000000141749573	13137672,31906
2,90	0,90832	623,0001	606,3220	16969,71102	531460,2890	6,0	0,000039	0,0000073	0,0000	14,6139	0,0000000141749573	13174901,92574
3,00	0,91557	623,0001	607,7834	16969,71106	531460,2889	6,0	0,000036	0,0000067	0,0000	13,3126	0,0000000141749573	13209186,95201
3,10	0,92225	623,0001	609,1146	16969,71110	531460,2889	6,0	0,000033	0,0000061	0,0000	12,1306	0,0000000141749573	13240760,29190
3,20	0,92840	623,0001	610,3277	16969,71114	531460,2889	6,0	0,000031	0,0000057	0,0000	11,0566	0,0000000141749573	13269836,41931
3,30	0,93406	623,0001	611,4333	16969,71117	531460,2888	6,0	0,000028	0,0000052	0,0000	10,0800	0,0000000141749573	13296612,84486
3,40	0,93928	623,0001	612,4413	16969,71120	531460,2888	6,0	0,000026	0,0000048	0,0000	9,1917	0,0000000141749573	13321271,45758
3,50	0,94408	623,0001	613,3605	16969,71123	531460,2888	6,0	0,000024	0,0000044	0,0000	8,3833	0,0000000141749573	13343979,76046
3,60	0,94850	623,0001	614,1989	16969,71126	531460,2887	6,0	0,000022	0,0000041	0,0000	7,6475	0,0000000141749573	13364892,00825
3,70	0,95258	623,0001	614,9636	16969,71128	531460,2887	6,0	0,000020	0,0000038	0,0000	6,9773	0,0000000141749167	13384150,25535
3,80	0,95633	623,0001	615,6613	16969,71130	531460,2887	6,0	0,000019	0,0000035	0,0000	6,3668	0,0000000141749167	13401885,32069
3,90	0,95978	623,0001	616,2980	16969,71132	531460,2887	6,0	0,000017	0,0000032	0,0000	5,8105	0,0000000141749167	13418217,67644
4,00	0,96296	623,0001	616,8791	16969,71134	531460,2887	6,0	0,000016	0,0000029	0,0000	5,3035	0,0000000141749167	13433258,26633
4,10	0,96589	623,0001	617,4094	16969,71136	531460,2886	6,0	0,000015	0,0000027	0,0000	4,8413	0,0000000141749167	13447109,25925
4,20	0,96859	623,0001	617,8935	16969,71137	531460,2886	6,0	0,000013	0,0000025	0,0000	4,4198	0,0000000141749167	13459864,74335
4,30	0,97107	623,0001	618,3355	16969,71139	531460,2886	6,0	0,000012	0,0000023	0,0000	4,0354	0,0000000141749167	13471611,36509
4,40	0,97336	623,0001	618,7391	16969,71140	531460,2886	6,0	0,000011	0,0000021	0,0000	3,6847	0,0000000141749167	13482428,91785
4,50	0,97547	623,0001	619,1075	16969,71141	531460,2886	6,0	0,000010	0,0000019	0,0000	3,3648	0,0000000141749167	13492390,88397
4,60	0,97741	623,0001	619,4440	16969,71142	531460,2886	6,0	0,000010	0,0000018	0,0000	3,0728	0,0000000141749167	13501564,93388
4,70	0,97920	623,0001	619,7513	16969,71144	531460,2886	6,0	0,000009	0,0000016	0,0000	2,8064	0,0000000141749167	13510013,38579
4,80	0,98084	623,0001	620,0319	16969,71144	531460,2886	6,0	0,000008	0,0000015	0,0000	2,5632	0,0000000141749167	13517793,62903
4,90	0,98236	623,0001	620,2882	16969,71145	531460,2885	6,0	0,000008	0,0000014	0,0000	2,3412	0,0000000141749167	13524958,51384
5,00	0,98375	623,0001	620,5224	16969,71146	531460,2885	6,0	0,000007	0,0000013	0,0000	2,1386	0,0000000141749167	13531556,71043
5,10	0,98504	623,0001	620,7362	16969,71147	531460,2885	6,0	0,000006	0,0000012	0,0000	1,9535	0,0000000141749167	13537633,03955
5,20	0,98622	623,0001	620,9316	16969,71148	531460,2885	6,0	0,000006	0,0000011	0,0000	1,7846	0,0000000141749167	13543228,77697
5,30	0,98731	623,0001	621,1100	16969,71148	531460,2885	6,0	0,000005	0,0000010	0,0000	1,6303	0,0000000141749167	13548381,93386
5,40	0,98831	623,0001	621,2731	16969,71149	531460,2885	6,0	0,000005	0,0000009	0,0000	1,4895	0,0000000141749167	13553127,51500
5,50	0,98924	623,0001	621,4220	16969,71149	531460,2885	6,0	0,000005	0,0000009	0,0000	1,3608	0,0000000141749167	13557497,75654
5,60	0,99009	623,0001	621,5581	16969,71150	531460,2885	6,0	0,000004	0,0000008	0,0000	1,2433	0,0000000141749167	13561522,34502
5,70	0,99087	623,0001	621,6824	16969,71150	531460,2885	6,0	0,000004	0,0000007	0,0000	1,1359	0,0000000141749167	13565228,61897
5,80	0,99160	623,0001	621,7960	16969,71151	531460,2885	6,0	0,000004	0,0000007	0,0000	1,0379	0,0000000141749167	13568641,75467
5,90	0,99226	623,0001	621,8998	16969,71151	531460,2885	6,0	0,000003	0,0000006	0,0000	0,9483	0,0000000141749167	13571784,93714
6,00	0,99287	623,0001	621,9946	16969,71151	531460,2885	6,0	0,000003	0,0000006	0,0000	0,8665	0,0000000141749167	13574679,51763

Tabel Iterasi Bagian 3

z (m)	x	T (K)	Ts (K)	∫ ΔCP.dT (j/mol)	(-ΔHR)	P (atm)	ra, Kmol/ m3 jam	dx/dz	dT/dz	dTs/dz	dP/dz	Fi.Cpi
6,10	0,99344	623,0001	622,0813	16969,71152	531460,2885	6,0	0,000003	0,0000005	0,0000	0,7918	0,0000000141749167	13577345,15869
6,20	0,99396	623,0001	622,1605	16969,71152	531460,2885	6,0	0,000003	0,0000005	0,0000	0,7235	0,0000000141749167	13579799,96769
6,30	0,99443	623,0001	622,2328	16969,71152	531460,2885	6,0	0,000002	0,0000004	0,0000	0,6611	0,0000000141749167	13582060,61986
6,40	0,99487	623,0001	622,2989	16969,71153	531460,2885	6,0	0,000002	0,0000004	0,0000	0,6041	0,0000000141749167	13584142,47153
6,50	0,99528	623,0001	622,3593	16969,71153	531460,2885	6,0	0,000002	0,0000004	0,0000	0,5520	0,0000000141749167	13586059,66447
6,60	0,99565	623,0001	622,4145	16969,71153	531460,2885	6,0	0,000002	0,0000003	0,0000	0,5044	0,0000000141749167	13587825,22194
6,70	0,99600	623,0001	622,4650	16969,71153	531460,2885	6,0	0,000002	0,0000003	0,0000	0,4609	0,0000000141749167	13589451,13717
6,80	0,99631	623,0001	622,5111	16969,71153	531460,2885	6,0	0,000002	0,0000003	0,0000	0,4212	0,0000000141749167	13590948,45478
6,90	0,99660	623,0001	622,5532	16969,71154	531460,2885	6,0	0,000001	0,0000003	0,0000	0,3849	0,0000000141749167	13592327,34590
7,00	0,99687	623,0001	622,5917	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,3518	0,0000000141749167	13593597,17715
7,10	0,99712	623,0001	622,6269	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,3215	0,0000000141749167	13594766,57435
7,20	0,99735	623,0001	622,6590	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,2938	0,0000000141749167	13595843,48106
7,30	0,99756	623,0001	622,6884	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,2685	0,0000000141749167	13596835,21260
7,40	0,99775	623,0001	622,7152	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,2453	0,0000000141749167	13597748,50567
7,50	0,99793	623,0001	622,7398	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,2242	0,0000000141749167	13598589,56417
7,60	0,99809	623,0001	622,7622	16969,71154	531460,2885	6,0	0,000001	0,0000002	0,0000	0,2049	0,0000000141749167	13599364,10129
7,70	0,99824	623,0001	622,7827	16969,71154	531460,2885	6,0	0,000001	0,0000001	0,0000	0,1872	0,0000000141749166	13600077,37838
7,80	0,99838	623,0001	622,8014	16969,71155	531460,2885	6,0	0,000001	0,0000001	0,0000	0,1711	0,0000000141749166	13600734,24064
7,90	0,99851	623,0001	622,8185	16969,71155	531460,2885	6,0	0,000001	0,0000001	0,0000	0,1564	0,0000000141749166	13601339,15007
8,00	0,99863	623,0001	622,8341	16969,71155	531460,2885	6,0	0,000001	0,0000001	0,0000	0,1429	0,0000000141749166	13601896,21573
8,10	0,99874	623,0001	622,8484	16969,71155	531460,2885	6,0	0,000001	0,0000001	0,0000	0,1306	0,0000000141749166	13602409,22171
8,20	0,99884	623,0001	622,8615	16969,71155	531460,2885	6,0	0,000000	0,0000001	0,0000	0,1194	0,0000000141749166	13602881,65280
8,30	0,99893	623,0001	622,8734	16969,71155	531460,2885	6,0	0,000000	0,0000001	0,0000	0,1091	0,0000000141749166	13603316,71815
8,40	0,99901	623,0001	622,8843	16969,71155	531460,2885	6,0	0,000000	0,0000001	0,0000	0,0997	0,0000000141749166	13603717,37313
8,50	0,99909	623,0001	622,8943	16969,71155	531460,2885	6,0	0,000000	0,0000001	0,0000	0,0911	0,0000000141749166	13604086,33932
8,60	0,99916	623,0001	622,9034	16969,71155	531460,2884	6,0	0,000000	0,0000001	0,0000	0,0833	0,0000000141749166	13604426,12308
8,70	0,99923	623,0001	622,9117	16969,71155	531460,2884	6,0	0,000000	0,0000001	0,0000	0,0761	0,0000000141749166	13604739,03251
8,80	0,99929	623,0001	622,9193	16969,71155	531460,2884	6,0	0,000000	0,0000001	0,0000	0,0695	0,0000000141749166	13605027,19318
8,90	0,99935	623,0001	622,9263	16969,71155	531460,2884	6,0	0,000000	0,0000001	0,0000	0,0636	0,0000000141749166	13605292,56251
9,00	0,99940	623,0001	622,9327	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0581	0,0000000141749166	13605536,94313

Tabel Iterasi Bagian 4

z (m)	x	T (K)	Ts (K)	∫ ΔCP.dT (j/mol)	(-ΔHR)	P (atm)	ra, Kmol/ m3 jam	dx/dz	dT/dz	dTs/dz	dP/dz	Fi.Cpi
9,10	0,99945	623,0001	622,9385	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0531	0,0000000141749166	13605761,99509
9,20	0,99949	623,0001	622,9438	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0485	0,0000000141749166	13605969,24715
9,30	0,99953	623,0001	622,9486	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0443	0,0000000141749166	13606160,10713
9,40	0,99957	623,0001	622,9531	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0405	0,0000000141749166	13606335,87153
9,50	0,99960	623,0001	622,9571	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0370	0,0000000141749166	13606497,73429
9,60	0,99963	623,0001	622,9608	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0338	0,0000000141749166	13606646,79494
9,70	0,99966	623,0001	622,9642	16969,71155	531460,2884	6,0	0,000000	0,0000000	0,0000	0,0309	0,0000000141749166	13606784,06601

Dari hasil iterasi diatas didapat nilai :

Konversi	= 0,99953
Suhu gas masuk (T in)	= 623 K
Suhu gas keluar (T out)	= 623,0001
Z (panjang pipa tube)	= 9,300 m
Tekanan masuk (P in)	= 6 atm
Tekanan keluar (P out)	= 6 atm
Diameter *shell* (IDS)	= 363,7093 cm
Suhu pendingin masuk (Ts in)	= 298 K
Suhu pendingin keluar (Ts out)	= 622,9486 K

19. *Mechanical Design*

1. *Tube*

IPS	= 2 in
OD	= 2,38 in
Sch Number	= 40
ID	= 2,067 in
Flow area	= 3,350 in^2
Surface per lin ft	
Outside	= 0,622 ft^2/ft
Inside	= 0,542 ft^2/ft
Weight per lin	= 3,6600 lb steel
Panjang pipa	= 366,1419

Susunan pipa = Triangular pitch

Jumlah pipa = 2100

Pitch = 2,9750 in

Clearance = 0,5950 in

Cek SC yang dipilih :

Untuk Sc number 40

IDt = 2,0670 in

ODt = 2,3800 in

Ketebalan = 0,1565 in

$$TebalTube = \frac{P \times r}{f \times E - 0{,}6P} + C$$ = 0,12500 in

Dari tabel 13.1, P.251, Brownell, 1959. diperoleh

Tekanan yang diizinkan (f) = 17500 psi

Efisiensi pengelasan (E) = 0,85 (double welded butt joint, tabel 13.2. P.254)

Faktor korosi (c) = 0,125 in

2. *Shell*

a) Tekanan design

tekanan operasi = 6 atm

= 88,20 psi

= 6,0795 bar

tekanan desain = 105,8400 psi

= 91,1400 psig

= 7,2 atm

b) Bahan konstruksi *shell*

Dipilih material *Carbon Steel SA 283 Grade C* (Brownell, P.253)

pertimbangan :

- reaktor tidak berisi larutan maupun gas yang beracun
- suhu operasi antara 20 sampai dengan 650 ^oF

F	C
20	2,7778
650	632,7778

c) Tebal dinding *shell*

Tebal dinding *shell* dihitung dengan persamaan :

$$ts = \frac{Pxr}{fxE - 0.6P} + c$$ (Eq 13.1, P.254, Brownell, 1959)

dimana :

Ts : tebal dinding *shell* (in)

P : tekanan *design* (psi)

r (IDs/2) : radius dalam *shell* (in)

E : efisiensi sambungan

f : *allowable working stress* (psi)

c : faktor korosi (in)

Dari tabel 13.1, P.251, Brownell, 1959, diperoleh :

Tekanan yang diizinkan (f) = 17500 psi

Efisiensi pengelasan (E) = 0,85 (double welded butt joint, tabel 13.2, P.254)

Faktor korosi (c) = 0,125 in

Dengan IDs = 143,1927 in

= 3,637093382 m

Tebal *shell* (ts) = 0,6366 in

Dipilih tebal dinding standar = ¾ in

= 0,75 in

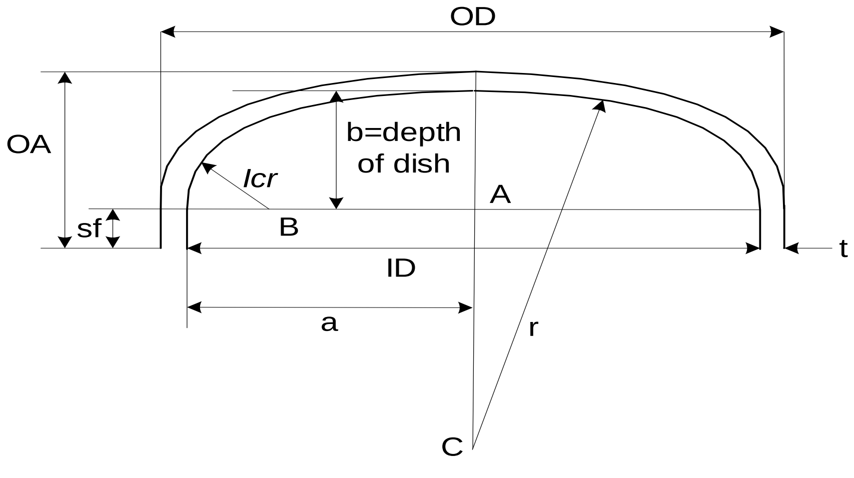
ODs = IDs + 2 (tebal shell)

= 144,6927 in

Dari tabel 5.7, P.90, Brownell, 1959. Dipilih OD standar = 144 in

3. Head Reaktor

a. bentuk head : *torispherical* digunakan untuk tekanan operasi hingga 15 bar dan harganya cukup ekonomis. (Coulson, P.818) digunakan untuk *vessel* dengan tekanan antara 15-200 psig. (Brownell and Young, 1959)



b. Bahan konstruksi *head*

Dipilih material *Carbon Steel SA 212 Grade B*

pertimbangan :

- reaktor tidak berisi larutan maupun gas yang beracun.
- suhu operasi antara 20 sampai dengan 650 ^oF

c. Tebal *Head* (tH)

untuk *elipstical dished head*, Tebal head dihitung dengan persamaan 13.10 (Brownell and Young,1959)

$$tH = \frac{P.IDs}{2.f.E - 0,2P} + c$$

dimana :

P	: Tekanan perancangan (psi)
f	: Tekanan maksimum yang diijinkan pada bahan (psi)
C	: *Joint efficiency* (in)
E	: *Corrosion allowance* (in)

Dipilih material *Carbon Steel SA 283 Grade C*, dari tabel 13.1, P.215, Brownell and Young diperoleh :

Tekanan yang diizinkan (f)	= 17500 psi
Efisiensi pengelasan (E)	= 0,85
Faktor korosi (c)	= 0,125 in

Tebal *head* reaktor (tH) = 0,6348 in

Dipilih tebal *head* standar = ½ in

= 0,5 in

c. Tinggi *Head* (hH)

dari tabel 5.7 Brownell and Young hal.90

ODs = 144 in

ts = 0,75 in

didapat :

icr = 8 ¾ in

= 8,75 in

r = 132

a = IDs/2

= 71,5963 in

AB = a – icr

= 67,9713 in

BC = r – icr

= 128,3750 in

AC = $(BC^2-AB^2)^{1/2}$

= 108,9038 in

b = r – AC

= 23,0962 in

Dari tabel 5.6 Brownell and Young hal. 88 dengan th ½ in didapatkan sf = 1 ½ - 2 ½ in

perancangan digunakan sf = 2 in

hH = th + b + sf

= 25,5962 in

= 2,1330 ft

= 0,6501 m

5. Volume Reaktor (VR)

a) Volume *head* (VH)

VH = 0,000049 x IDs^3.....(Eq 5.11, P.88, Brownell, 1959)

= 143,8660 in^3

= 2,3575 x 10^{-3} m^3

b) Volume *shell* (VS)

VS = π/4. $(IDs)^4$.Z

= 5893324,5517 in^3

= 96,5745 m^3

c) Volume Reaktor (VR)

VR = Volume *shell* + (2 x Volume *head*)

= 96,5792 m^3

6. Spesifikasi *Nozzle*

dipilih jenis pipa : *Carbon Steel* (karena harganya lebih murah dan komponen yang melewati pipa tidak bersifat korosif).

a) Diameter saluran gas umpan

$$D_{opt} = 293\,G^{0,53}\,\rho^{-0,37}$$ ....(Coulson and Richardson vol.6, 1983, P.221, Eq 5.14)

dimana :

G = kecepatan gas umpan = 25,068 kg/s

ρ = densitas gas umpan mix = 3,7439 kg/m^3

Sehingga :

D opt = 991,4635 mm

= 39,0340 in

Dari Tabel.11, p.844, Kern, 1980, dipilih ukuran standar (Sch 80)

ID = 7,625 in

OD = 8,625 in

b) Diameter saluran gas keluar

Komposisi keluar reaktor (gas)

Komponen	kmol/jam	yi	BM	BM.Yi
O_2	66536,5306	0,7373	31,9988	23,5917
N_2	16441,1996	0,1822	28	5,1010
CO	1260,3286	0,0140	28	0,3910
CO_2	938,8399	0,0104	44	0,4577
Ar	1,1184	0,0000	39,998	0,0005
o-xylene	1,3033	0,0000	106	0,0015
m-xylene	627,1272	0,0069	106,16	0,7377
$C_8H_4O_3$	2811,845688	0,0312	148	4,6113
$C_8H_8O_2$	5,702145026	0,0001	116	0,0073
$C_8H_6O_2$	6,586960633	0,0001	134	0,0098
$C_7H_6O_2$	23,98833425	0,0003	122	0,0324
$C_5H_6O_4$	3,195167471	0,0000	130	0,0046
$C_4H_2O_3$	96,34658836	0,0011	98	0,1046
H_2O	1493,126338	0,0165	18	0,2978
Total	90247,2389	0,9508	384,1568	30,2813

Densitas gas out mix (ρ) = 3,5565 kg/m^2

(T = 572,1266 K dan P = 1,5 atm)

$$D_{opt} = 293\, G^{0,53} \rho^{-0,37}$$ ....(Coulson and Richardson vol.6, 1983, P.221, Eq 5.14)

dimana :

G = kecepatan gas out = 25,0687 kg/s

ρ = densitas gas out mix = 3,5565 kg/m^3

Sehingga :

D opt = 1010,4822 mm

= 39,7828 in

Dari Tabel.11, p.844, Kern, 1980, dipilih ukuran standar (Sch 40)

ID = 10,02 in

OD = 10,75 in

c) Diameter pendingin masuk

$$\rho\ p = 1.3644 - (9.7073 x 10^{-4}\ Tin)$$

rho p = 1,0771 gr/cm^3

= 1077,12246 kg/m^3

$$D_{opt} = 293\, G^{0,53} \rho^{-0,37}$$ ....(Coulson and Richardson vol.6, 1983, P.221, Eq 5.14)

dimana :

G = kecepatan aliran pendingin = 25,0687 kg/s

ρ = densitas pendingin = 3,5565 kg/m^3

Sehingga :

D opt = 82,6863 mm

= 3,2554 in

Dari Tabel.11, p.844, Kern, 1980, dipilih ukuran standar (Sch 40)

ID = 4,026 in

OD = 4,5 in

d) Diameter pendingin keluar

$$\rho\ p = 1.3644 - (9.7073 x 10^{-4}\ Tin)$$

T pendingin out = 622,9486 K

rho p = 0,7597 gr/cm^3

= 759,6851 kg/m^3

$$D_{opt} = 293\, G^{0,53} \rho^{-0,37}$$ ....(Coulson and Richardson vol.6, 1983 P.221, Eq 5.14)

dimana :

G = kecepatan aliran pendingin = 12,0281 kg/s

ρ = densitas pendingin = 759,6851 kg/m^3

Sehingga :

D opt = 94,0887 mm

= 3,7043 in

Dari Tabel.11, p.844, Kern, 1980, dipilih ukuran standar (Sch 40)

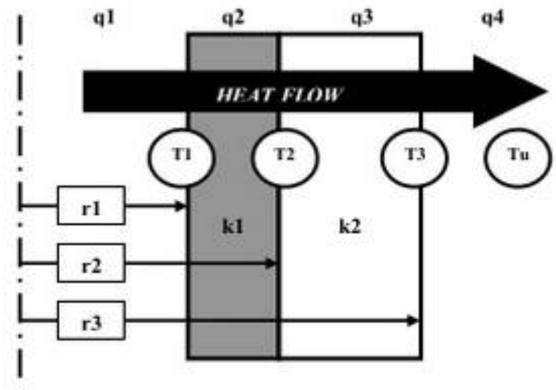
ID = 4,026 in

OD = 4,5 in

Perancangan Isolasi Reaktor

Isolasi perlu ditambahkan pada dinding reaktor untuk keamanan (*safety*) para operator yang berada dekat dengan reaktor mengingat reaksi eksotermis yang terjadi bisa menimbulkan panas hingga temperatur 717 K (444 C). Selain itu isolasi juga berfungsi untuk menjaga kondisi operasi (suhu) peralatan agar tidak terpengaruh fluktuasi suhu lingkungan, serta melindungi material alat dari kemungkinan korosi.

2. Perpindahan panas *steady* state, sehingga q1 = q2= q3



keterangan:

r_1 = jari-jari dalam *shell*

r_2 = jari-jari luar *shell*

r_3 = jari-jari luar isolator

q_1 = konveksi dari fluida ke *shell*

q_2 = konduksi melalui *shell*/dinding reaktor

q_3 = konduksi melalui isolator

q_4 = konveksi dari permukaan luar isolator ke udara

T_1 = suhu dinding dalam reaktor

T_2 = suhu dinding luar reaktor

T_3 = suhu dinding luar isolator

Tu = suhu udara luar

Bahan dinding kolom adalah baja (carbon steel) dengan spesifikasi:

k = 54 W/m K (Appendix A-2, Holman 1986)

ρ = 7,833 kg/m3 (Appendix A-2, Holman 1986)

ε = 0,61 (Appendix A-10, Holman 1986)

Bahan isolasi yang dipilih adalah asbestos (karena memiliki nilai konduktivitas thermal rendah dan harga yang murah) dengan spesifikasi :

kis = 0,161 W/m K (Appendix A-3, Holman 1986)

ρis = 570 kg/m3 (Appendix A-3, Holman 1986)

εis = 0,96 (Appendix A-10, Holman 1986)

Bila suhu udara luar diasumsikan 30 °C dan diinginkan suhu permukaan luar isolasi (T_3) = 50 °C, maka diperoleh T bulk (Tf)

$$T_f = \frac{T_3 + T_u}{2}$$

Dimana :

T_3 = 50 ^oC

= 323,15 K

Tu = 30 ^oC

= 303,15 K

maka, nilai T bulk adalah

Tf = 313,15 K

Sifat-sifat udara pada suhu 313 K (40 ^oC) diperoleh dengan cara interpolasi data dari Daftar A-5 Holman (1986)

T, K	**ρ, kg/m^3**	**C_p, kj/kg. ^oC**	**μ x 10^5, kg/m.s**	**v x 10^6, m^2/s**	**k, W/m C**	**Pr**
300	1,1774	1,0057	1,8462	15,69	0,02624	0,708
350	0,998	1,009	2,075	20,76	0,03003	0,697

Sehingga sifat-sifat udara pada suhu 313 adalah

ρud = 1,1302 kg/m^3

Cp = 1,0066 kj/kg.K

μ = 1,90637E-05 kg/m.s

v = 1,70234E-05 m^2/s

kud = 0,0272 W/m.K

Pr = 0,7051

Menghitung Bilangan Grasshof

Persamaan yang digunakan : $G_r = \frac{g\beta(T_3 - T_u)L^3}{v^2}$ dimana $\beta = \frac{1}{T_f}$

Dengan :

g = 9,807 m/s^2

β = 0,0032 K^{-1}

T_3 = 323,15 K

Tu = 303,15 K

L = 10,6003 m

v = 1,70234E-05 m^2/s

Maka diperoleh nilai bilangan grasshof sebesar :

G_r : 2,57439 x 10^{12}

Menghitung Bilangan Nusselt

Persamaan yang digunakan :

$$N_u = 0{,}1(G_r P_r)^{1/3}$$

Dengan :

G_r = 2,57439 x 10^{12}

Pr = 0,7051

Maka diperoleh nilai bilangan nusselt sebesar :

Nu = 1219,8592

Menghitung koefisien perpindahan panas konveksi (h_c)

$$h_c = \frac{N_u k_{ud}}{L}$$

Dengan :

Nu = 1219,8592

k_{ud} = 0,0272 W/m.K

L = 10,6003 m

Maka diperoleh nilai koefisien perpindahan panas konveksi sebesar

h_c = 3,1344 W/m^2 K

Menghitung koefisien perpindahan panas (h_r)

$$h_r = \frac{\varepsilon_{is}\sigma(T_3{}^4 - T_u{}^4)}{(T_3 - T_u)}$$

Dengan :

ε_{is} = 0,96

σ = 5,6690 x 10^{-8} W/m^2 K4

T_3 = 323,15 K

Tu = 303,15 K

maka, diperoleh nilai koefisien perpindahan panas radiasi

h_r = 6,6916 W/m^2 K

Menentukan suhu T_2 dari neraca panas di setiap lapisan :

$$q_2 = \frac{2\pi L(T_1 - T_2)k}{\ln\left({}^{R_2}/_{R_1}\right)} \qquad q_3 = \frac{2\pi L(T_2 - T_3)k_{is}}{\ln\left({}^{R_3}/_{R_2}\right)} \qquad q_4 = (h_c + h_r)2\pi R_3 L(T_3 - T_u)$$

Karena *steady state* maka q_2=q_3=q_4

Untuk q_2 = q_4, maka :

$$\frac{2\pi L(T_1 - T_2)k}{\ln\left({}^{R_2}/_{R_1}\right)} = (h_c + h_r)2\pi R_3 L(T_3 - T_u)$$

$$R_3 = \frac{(T_1 - T_2)k}{(h_c + h_r)(T_3 - T_u)\ln\left({}^{R_2}/_{R_1}\right)}$$

Untuk q_3 = q_4, maka

$$\frac{2\pi L(T_2 - T_3)k_{is}}{\ln\left({}^{R_3}/_{R_2}\right)} = (h_c + h_r)2\pi R_3 L(T_3 - T_u)$$

$$R_3{}' = \frac{(T_2 - T_3)k_{is}}{(h_c + h_r)(T_3 - T_u)\ln\left({}^{R_3}/_{R_2}\right)}$$

kemudian trial nilai T_2 sampai nilai $R_3 = R_3'$

dengan :

k = 54 W/m K

k_{is} = 0,161 W/m K

hc = 3,1344 W/m^2 K

hr = 6,6917 W/m^2 K

R_2 = 1,8288 m

R_1 = 1,818546691 m

T_1 = 623 K

T_3 = 323,15 K

Tu = 303,15 K

T_2 tebak = 622,999987 K

tebak jari-jari luar isolator

R_3 = 0,0006353 m

R_3' = -0,0308414 m

Hasil trial diperoleh :

T_2 = 622,999987 K

= 349,849987 C

R_3 = 0,0006353 m

= 0,06353 cm

Jadi tebal isolasi yang digunakan adalah

= 1,8281647 m

= 182,81647cm

Menghitung panas hilang ke lingkungan (Q_{losses})

$Q_{losses} = Q_4$ = 8,311825766 j/s