

LAMPIRAN A

Perancangan Menara Distilasi (D-01)

* Mencari Rmin

Dengan komposisi umpan masuk

Komponen	n (kmol/jam)	fraksi mol (xf)	P° (mmHg)	Pt (mmHg)	K	α	$\frac{\alpha \cdot Xf}{\alpha - \theta}$
Benzen	259.2011	0.850353788	836.2891462	760	1.100380456	2.560E+00	1.092E+00
Toluen	45.6145	0.149646212	326.6930491	760	0.429859275	1	-1.092E+00
							5.198E-04

$$T = 356.5206019$$

$$\theta = 0.566931195$$

Dengan komposisi distilat

Komponen	n (kmol/jam)	fraksi mol (Yi)	P° (mmHg)	Pt (mmHg)	K	α	$\frac{\alpha \cdot XD}{\alpha - \theta}$
Benzen	259.0943	0.998303886	2.881647102	760	0.003791641	1.16734907	1.9409301
Toluen	0.4402	0.001696114	2.468539339	760	0.003248078	1	0.0039165
							1.9448466

$$T = 353.4429973$$

$$\theta = 0.566931195$$

$$R_{min} + 1 = 1.944846577$$

$$R_{min} = 0.944846577 \quad L_o = 1.417269866 \quad D$$

$$R/R_{min} = 1.5$$

$$R = 1.5 \quad R_{min}$$

$$R = 1.417269866$$

$$R = L_o/D$$

$$1.417269866 = L_o/D \quad D = 259.5345 \quad \text{kmol/jam}$$

$$L_o \text{ total} = 367.830426 \quad \text{kmol/jam}$$

$$L_o \text{ benzene} = 367.2065438 \text{ kmol/jam}$$

$$L_o \text{ toluene} = 0.623882195 \text{ kmol/jam}$$

$$D \text{ benzen} = 259.0943 \text{ kmol/jam}$$

$$D \text{ toluene} = 0.4402 \text{ kmol/jam}$$

$$V1 = L_o + D$$

$$V1 = 367.830426 + 259.5345$$

$$V1 = 627.364926 \text{ kmol/jam}$$

* Neraca energi di kondensor :

$$V1.HV(g) = L_o.h_o + D.h_D + Q_c \quad h_o = h_D = h_L$$

$$V1.HV(g) = (L_o + D)HL + Q_c \quad V1 = L_o + D$$

$$Q_c = V1.HV - (L_o + D)HL$$

$$\Delta H = AT + \left(\frac{B}{2}\right)T^2 + \left(\frac{C}{3}\right)T^3 + \left(\frac{D}{4}\right)T^4 + \left(\frac{E}{5}\right)T^5$$

A. HEAT CAPACITY OF GAS

$$T_{ref} = 25^\circ C$$

$$298 \text{ K}$$

Komponen	A	B	C	D	E	Tmin	Tmax
Benzena	-31.368	-0.4746	-0.00031137	-8.5237E-08	-5.0524E-12	200	1500
Toluena	-24.097	0.52187	-0.00029827	6.122E-08	1.2576E-12	200	1500
Hidrogen	25.399	0.020178	-0.000038549	3.188E-08	-8.7585E-12	250	1500
Metana	34.942	-0.039957	0.00019184	-1.5303E-07	3.9821E-11	50	1500

$$T = 353.4429973 \text{ K}$$

$$T_{ref} = 298 \text{ K}$$

Komponen	n(kmol/jam)	$\int_{T_{ref}}^T C_p dT$	Hv(g) (kJ/jam)
Benzen	626.3008438	-12313.57999	7712005.541
Toluen	1.064082195	6448.649794	6861.893428
			7718867.434

* V1.HL

B. HEAT CAPACITY OF LIQUID

Komponen	A	B	C	D	Tmin	Tmax
Benzena	-31.662	1.3043	-0.0036078	3.8243E-06	280	506
Toluena	83.703	0.51666	-0.001491	1.9725E-06	197	533
Hidrogen	50.607	-6.1136	0.3093	-0.004148	14	32
Metana	-0.018	1.1982	-0.0098722	0.00003167	92	172

$$T = 353.4429973 \text{ K}$$

$$T_{ref} = 298 \text{ K}$$

$$\Delta H = A T + (B/2) T^2 + (C/3) T^3 + (D/4) T^4 + (E/5) T^5$$

Komponen	n (kmol/jam)	$\int_{T_{ref}}^T C_p dT$	HL (l) (kJ/jam)
Benzen	626.3008438	7906.129394	4951615.511
Toluen	1.064082195	8986.166182	9562.019436
			4961177.53

$$Q_c = 2757689.904 \text{ kJ/jam} \quad \text{Kebutuhan air} = 1648.483781 \text{ kg/jam}$$

$$T_{in} = 30^\circ\text{C} = 303 \text{ K} \quad n_{air} = 91.58243225 \text{ kmol/jam}$$

$$T_{out} = 50 \text{ }^\circ\text{C} = 323 \text{ K}$$

$$C_p \text{ air} = 1505.578 \text{ kJ/kmol K}$$

B. HEAT CAPACITY OF LIQUID

Komponen	A	B	C	D	Tmin	Tmax
Benzena	-31,662	1,3043	-0,0036078	3,8243E-06	280	506
Toluena	83,703	0,51666	-0,001491	1,9725E-06	197	533
Hidrogen	50,607	-6,1136	0,3093	-0,004148	14	32
Metana	-0,018	1,1982	-0,0098722	0,00003167	92	172

$$HF + QR = HD + HW + QC \quad \Delta H = A T + \left(\frac{B}{2}\right) T^2 + \left(\frac{C}{3}\right) T^3 + \left(\frac{D}{4}\right) T^4 +$$

$$\left(\frac{E}{5}\right) T^5$$

*HF

Komponen	n (kmol/jam)	$\int_{T_{ref}}^T C_p dT$	HF (l) (kJ/jam)
Benzen	259,2011	8360,948023	2167166,924
Toluen	45,6145	9501,536404	433407,8323
			2600574,757

$$T = 356,5206019 \text{ K}$$

$$T_{ref} = 298 \text{ K}$$

*HD

Komponen	n (kmol/jam)	$\int_{T_{ref}}^T C_p dT$	HF (l) (kJ/jam)
Benzen	259,0943	7906,129394	2048433,061
Toluen	0,4402	8986,166182	3955,710353
			2052388,771

$$T = 353,4429973 \text{ K}$$

$$T_{ref} = 298 \text{ K}$$

*HW

Komponen	n (kmol/jam)	$\int_{T_{ref}}^T C_p dT$	HF (l) (kJ/jam)
Benzen	0,0107	12471,18039	133,4416302
Toluen	45,2558	14155,11784	640601,1819
			640734,6236

$$T = 383,7761603 \text{ K}$$

$$T_{ref} = 298 \text{ K}$$

$$*QC = 2757689,904 \text{ kJ/jam}$$

$$QR = HD + HW + QC - HF$$

$$QR = 2850238,542 \text{ kJ/jam Kebutuhan steam} = 1966,08853 \text{ kg}$$

Feed :

$$X \text{ light key} = 0,850353788$$

$$X \text{ heavy key} = 0,149646212$$

Distilat :

$$X \text{ light key} = 0,998303886$$

$$X \text{ heavy key} = 0,001696114$$

Bottom :

$$X \text{ light key} = 0,000236378$$

$$X \text{ heavy key} = 0,999763622$$

$$\alpha \text{ top} = \frac{(K_{\text{lightkey}}/K_{\text{heavykey}})_{\text{distilat}}}{2,588855217} =$$

$$\alpha \text{ bottom} = \frac{(K_{\text{lightkey}}/K_{\text{heavykey}})_{\text{bottom}}}{2,340357977}$$

$$\alpha \text{ avg} = (\alpha \text{ top} \times \alpha \text{ bottom})^{0,5} = 2,461472722$$

* Rmin

$$R_{\text{min}} = 0,944846577$$

* Rtotal

$$R_{total} = 1,417269866$$

* Nmin (jumlah plate minimum)

$$N_{min} + 1 = \frac{\ln((X_{lightkey}/X_{heavykey})_{distilat} \times (X_{heavykey}/X_{lightkey})_{bottom})}{\ln \alpha_{avg}}$$

$$N_{min} + 1 = 16,35015234$$

$$N_{min} = 15,35015234$$

$$N_{min} = 16 \text{ plate}$$

* Jumlah plate teoritis (N)

Dari grafik $((N-N_{min})/(N+1))$ vs $((R-R_{min})/(R+1))$ (Perry figure 13-41 halaman 13-35)

$$(R-R_{min})/(R+1) = 0,195436718$$

$$(N-N_{min})/(N+1) = 0,6 \text{ Gilliland data points}$$

$$N = 44 \text{ plate DIBAGI 4}$$

* Jumlah plate aktual (N aktual)

$$\alpha \text{ paling ringan pada feed} = 2,560E+00$$

$$T_{avg} = 364,5799199 \text{ K} \quad 91,57991986 \text{ C} \quad 197 \text{ F}$$

Data viskositas (Yaws)

Komponen	A	B	C	D
Benzena	-7,4005	1181,5	0,014888	-0,000013713
Toluena	-5,1649	810,68	0,010454	-0,000010486

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

Komponen Feed	n (kmol)	Xi	μ pada Tavg	μ_i (cP)
Benzena	259,2011	0,850353788	0,278849754	0,237120945
Toluena	45,6145	0,149646212	0,299388525	0,044802359
	304,8156			0,281923303

$$\mu \times \alpha = 7,217E-01$$

Dari grafik 6-47 halaman 306 banchero :

$$\text{Effisiensi plate} = 57\% = 0,57$$

$$\text{Nactual} = (N/E_o) + 1$$

$$\text{Nactual} = 78,19298246$$

$$\text{Nactual} = 79 \text{ plate}$$

* Letak feed plate

Dengan persamaan Fenske :

$$N_r/N_s = \log((X_{lightkey}/X_{heavykey})_{distilat} \times$$

$$(X_{heavykey}/X_{heavykey})_{feed}) / \log((X_{lightkey}/X_{heavykey})_{feed} \times$$

$$(X_{heavykey}/X_{heavykey})_{bottom}))$$

$$N_r/N_s = 3.67088575$$

$$N_r/N_s = 3.67088575$$

$$N_r + N_s = \text{Nactual}$$

$$3.67088575 \quad N_s \quad + \quad N_s \quad = \quad 79$$

$$4.67088575 \quad N_s \quad = \quad 79$$

$$N_s \quad = \quad 16.91328031$$

$$N_s \quad = \quad 17$$

$$\text{Plate bawah berjumlah} \quad = \quad 17$$

$$\text{Plate atas berjumlah} \quad = \quad 62$$

Jadi, letak umpan (feed plate) masuk dari plate ke 17 dari bagian bawah.

* Penentuan diameter menara distilasi (D)

$$V_r \quad = \quad L_o + D$$

$$V_r \quad = \quad 627,364926 \quad \text{kmol/jam}$$

$$V_r \quad = \quad 48949,36138 \quad \text{kg/jam} = \quad 107933,3418 \quad \text{lb}$$

$$1 \text{ kg} = 2,205 \quad \text{lb}$$

* Penentuan diameter kolom destilasi

Penentuan diameter kolom atas :

$$\text{Diperkirakan diameter kolom} \quad = \quad 6-10 \text{ ft}$$

$$\text{Tray spacing} \quad = \quad 24 \quad \text{inch}$$

$$\text{Diambil tray spacing} \quad = \quad 24 \quad \text{inch}$$

Kecepatan alir maksimum :

Data densitas cair (Yaws) $A \cdot B^{-(1-T/T_c)^n}$ gr/mL

Komponen	A	B	n	T _c
Benzen	0,3009	0,2677	0,2618	562,16
Toluen	0,29999	0,27106	0,29889	591,79

pcairan atas

Komponen	n (kmol/jam)	Xi	ρi (gr/mL)	ρcampuran (gr/mL)
Benzen	259,0943	0,998303886	0,093739905	0,093580911
Toluen	0,4402	0,001696114	0,098068291	0,000166335
	259,5345			0,093747246

puap atas

Komponen	n(kmol/jam)	Xi	ρi (gr/L)	ρcampuran (gr/mL)
Benzen	259,0943	0,998303886	67,20043321	0,067086454
Toluen	0,4402	0,001696114	79,26204943	0,000134437
	259,5345			0,067220891

$$\text{Kecepatan alir maksimum} = V_m = K_v \sqrt{\frac{\rho_L - \rho_G}{\rho_G}} = 0,188455107 \quad \text{ft/s}$$

$$K_v = 0,3 \quad \text{ft/s}$$

(Figure 5.6, Peters, halaman 657)

$$\text{Kecepatan alir maksimum} = 0,188455107 \quad \text{ft/s}$$

Kecepatan alir aktual :

$$\text{Flooding yang diijinkan} = 65-80\% \quad (\text{Figure 16-7, Peters, halaman 658})$$

$$\text{Diambil kecepatan alir aktual} = 0,150764085 \quad \text{ft/s}$$

Diameter kolom atas :

$$D_{\text{atas}} = \sqrt{\frac{4 \times V_r}{\pi \times \rho_{\text{gas atas}} \times V_{\text{aktual}} \times 3600}}$$

$$D_{\text{atas}} = 7,769640797 \quad \text{ft} \quad 1 \text{ ft} = 0,305 \quad \text{m}$$

$$D_{\text{atas}} = 2,369740443 \quad \text{m}$$

Diameter kolom bawah :

$$\text{Diperkirakan diameter kolom} = 6-10 \quad \text{ft}$$

$$\text{Tray spacing} = 24 \quad \text{inch}$$

Diambil tray spacing = 24 inch

Data densitas cair (Yaws) $A \cdot B^{-(1-T/T_c)^n}$ gr/mL

Komponen	A	B	n	T _c
Benzen	0,3009	0,2677	0,2618	562,16
Toluen	0,29999	0,27106	0,29889	591,79

ρcairan bawah

Komponen	n (kmol/jam)	X _i	ρ _i (gr/mL)	ρcampuran (gr/mL)
Benzen	0,0107	0,000236378	0,091381355	2,16005E-05
Toluen	45,2558	0,999763622	0,095366759	0,095344217
	45,2665			0,095365817

ρuap bawah

Komponen	n(kmol/jam)	X _i	ρ _i (gr/L)	ρcampuran (gr/mL)
Benzen	0,0107	0,000236378	61,88899934	1,46292E-05
Toluen	45,2558	0,999763622	72,99728127	0,072980026
	45,2665			0,072994656

$$V_m = K_v \sqrt{\frac{\rho_L - \rho_G}{\rho_G}} = 0,166081015 \text{ ft/s}$$

Kecepatan alir maksimum :

$$V_m = 0,166081015 \text{ ft/s}$$

Kecepatan alir aktual :

$$V_{\text{aktual}} = 0,132864812 \text{ ft/s}$$

Diameter kolom bawah :

$$D_{\text{bawah}} = \sqrt{\frac{4 \times V_r}{\pi \times \rho_{\text{gas atas}} \times V_{\text{aktual}} \times 3600}}$$

$$= 7,942395366 \text{ ft}$$

$$= 2,422430587 \text{ m} = 95,37133444 \text{ in}$$

Maka diambil kolom distilasi yang jumlahnya paling besar yaitu

$$7,942395366 \text{ ft} = 8 \text{ ft} = 2,44 \text{ m}$$

Tower diameter = 8 ft

Tray spacing = 24 in Peters, halaman 684

* Tebal kolom distilasi (ts)

Bahan : Stainless Steel SA 167 Grade 11 Tipe 316

(Appendix D halaman 342, Brownell and Young)

$$P = 1 \text{ atm} = 14,6959 \text{ psi}$$

$$1 \text{ atm} = 14,6959 \text{ psi}$$

$$P_{\text{operasi}} = 1,1 \text{ atm} = 16,16549 \text{ psi}$$

$$r_i = 47,68566722 \text{ in}$$

$$t_s = 0,176424064$$

$$f = 18750 \text{ psi} \quad (\text{Brownell halaman 342})$$

$$\text{Diambil tebal standar shell} = E = 80\%$$

$$= 0,8$$

$$0,1875 \text{ in} \quad C = 0,125 \text{ in/10 tahun} (3/16)$$

(Tabel 5.6 brownell halaman 88)

$$\text{Shell : } t = 0,1875 \text{ in}$$

* Tebal tutup kolom distilasi

$$OD = 96 \text{ in}$$

Bentuk : Torispherical head (Flanged and dishead head)

(Brownell halaman 88)

$$i_{cr} = 5,875 \text{ in} \quad (57/8)$$

Bahan : Stainless Steel SA 167 Grade 11 Tipe 316

(Brownell Appendix D halaman 342) $r = 96$

in

OD = 95,74633444 in

ID = 95,37133444 in

Diambil diameter luar standar shell (Tabel 5.7. Brownell Young

halaman 90)

Head :

OD = 96 in

icr = 5,875 in (5 7 / 8)

r = 96 in

icr/r = 0,061197917

Berdasarkan brownell halaman 256-258 karena $icr/r > 6\%$, maka persamaan yang digunakan berdasarkan

persamaan 7.76 dan 7.77 halaman 138

$W = 1,760582305$

faktor intensifikasi stress untuk torispherical head

= 0,216083978 in

diambil tebal head standar = 0,25 in (1 / 4)

(Tabel 5.6 Brownell young)

* Tinggi penutup distilasi

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

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

$$b = OD/4$$

$$= 25,75 \text{ in} = 24 \text{ in}$$

$$\text{Tinggi head (Hh)} = OA = 0,654049647 \text{ m}$$

$$\text{Jumlah plate total} = \text{Naktual} = 79 \text{ plate}$$

$$\text{Jumlah plate} = \text{Naktual} - 1 = 78 \text{ plate dalam kolom}$$

$$\text{Tray spacing} = 24 \text{ in}$$

$$\text{Tinggi plate total dalam kolom} = \text{jumlah plate dalam kolom} \times \text{tray spacing}$$

$$= 1872 \text{ in}$$

$$= 47,54877432 \text{ m}$$

$$\text{Tinggi penutup kolom} = Hh = 0,654049647 \text{ m}$$

$$\text{Tinggi kolom distilasi} = H = \text{Tinggi plate total dalam kolom} + (2 \times Hh)$$

$$= 48,85687362 \text{ m}$$

Dengan demikian direncanakan kolom distilasi dengan spesifikasi :

$$\text{ID} = 7,769640797 \quad \text{ft} = 2,369740443 \quad \text{m}$$

$$1 \text{ ft} = 0,305 \text{ m}$$

$$\text{OD} = 7,942395366 \text{ f} = 2,422430587 \text{ m}$$

$$1 \text{ in} = 0,0254 \text{ m}$$

$$\text{Tebal kolom (ts)} = 0,1875 \text{ in} = 0,0047625 \text{ m}$$

$$\text{Tebal penutup (th)} = 0,25 \text{ in} = 0,00635 \text{ m}$$

$$\text{Tray spacing} = 24 \text{ in} = 0,6096 \text{ m}$$

$$\text{Tinggi penutup (Hh)} = 0,654049647 \text{ in} = 0,016612861 \text{ m}$$

$$\text{Tinggi kolom (H)} = 48,85687362 \text{ m} = 48,85687362 \text{ m}$$

$$\text{Jumlah plate} = 78 = 86$$

$$\text{Bentuk head} = \text{Torispherical head (Flanged and dishead head)}$$

$$\text{Bahan} = \text{Stainless Steel SA 167 Grade 11 Tipe 316}$$

