A 720 mol/h stream of toluene contaminated oil (composition 95, mole percent oil and 5 mole percent toluene) is to be cleaned up by countercurrent contact with air in a stripping tower operating at 25 C and atmospheric pressure. The tower will be packed with 1 inch plastic Pall rings. Exiting liquid should have toluene mole fraction equal to 0.001. entering air is pure and the flow rate of air used will be 1.078 times the minimum. The tower diameter is set at 17 inches. Under the proposed operating conditions H_x is 1.0 feet. What is the required packed height? Base your calculation on H_{Oy} and N_{Oy}

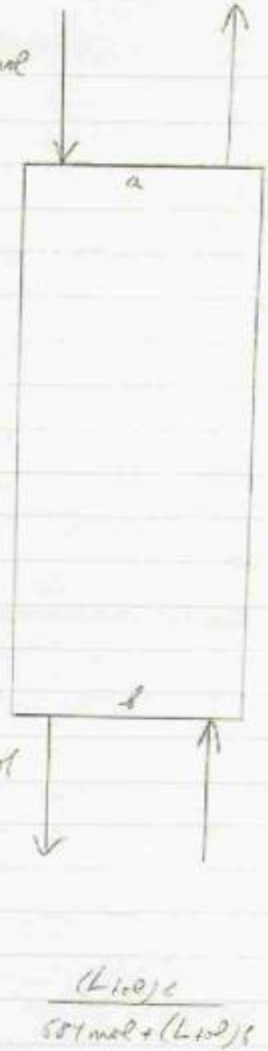
Information and data you may need: As usual, neglect any evaporation of oil as well as dissolution of air in the liquid. Assume validity of Raoult's Law for toluene. The saturated vapor pressure of toluene at 25 C is 0.0380 atm. The oil has molecular weight 170, density 0.730 g/cm^3 and viscosity 0.68 cP. Given the low toluene mole fractions throughout the tower, these properties of the pure oil may be used to approximate the corresponding properties of the liquid in the tower. A correlation for H_y is supplied.

1) (1 h basis)

(i) $L_a = 720$ mol
$x_a = 0.05$

$L_c = (0.95)(720)$
$= 684$ mol oil

$(L_{tol})_a = (0.05)(720)$
$= 36$ mol tol



V_c same
$(V_{tol})_a = 36 + 0 - 0.685$
$= 35.315$ mol
$y_a = ?$

$V_b = ? = V_c$
$y_b = 0$

L_c same
$x_b = 0.001$
$(L_{tol})_b = 0.685$ mol tol
$L_b = 684.685$ mol

$$0.001 = \frac{(L_{tol})_b}{684\text{ mol} + (L_{tol})_b} \Rightarrow (L_{tol})_b = 0.685\text{ mol}$$

(ii) Minimum air

$$(y_a)_{min\ air} = y^*(x_a) = \left(\frac{P_{tol}^{sat}}{P}\right) x_a$$ ← m

$$= (0.038\text{ atm})(0.05)/(1.0\text{ atm})$$

$$= 0.0019$$

$$0.0019 = \frac{35.315\text{ mol}}{(V_c)_{min} + 35.315\text{ mol}} \Rightarrow (V_c)_{min} = 18551.527\text{ mol}$$

(iii) Actual air

$$V_c = (1.078)(V_c)_{min} = (1.078)(18551.527\ mol)$$
$$= 19998.546\ mol \approx 20{,}000\ mol$$

Then $y_a = \dfrac{35.315}{35.315 + 20{,}000} = 0.001763$

(iv) Mass rate at main flows

$$(SG_x)_a = \left[(684\ mol/h\ oil)(170\ g/mol) + (36\ mol/h\ tol)(92.141\ g/mol)\right] \times \frac{1\ lbm}{453.59237\ g}$$
$$= 263.7\ lbm/h$$

$$(SG_y)_a = \left[(20{,}000\ mol/h\ air)(28.84\ g/mol) + (35.315\ mol/h\ tol)(92.141\ g/mol)\right] \times \frac{1\ lbm}{453.59237\ g}$$
$$= 1279\ lbm/h$$

$$(SG_x)_b = \left[(684\ mol/h\ oil)(170\ g/mol) + (0.685\ mol/h\ tol)(92.141\ g/mol)\right] \times \frac{1\ lbm}{453.59237\ g}$$
$$= 256.5\ lbm/h$$

$$(SG_y)_b = (20{,}000\ mol/h\ air)(28.84\ g/mol) \times \frac{1\ lbm}{453.59237\ g}$$
$$= 1272\ lbm/h$$

$\overline{(SG_x)}$ = arithmetic mean = 260.1 lbm/h

$\overline{(SG_y)}$ = arithmetic mean = 1275.5 lbm/h

$$\bar{G}_x = \frac{\overline{SG_x}}{S} = \frac{260.1\ lbm/h}{1.576\ ft^2} = 165\ \frac{lbm}{ft^2 h}$$

$$\bar{G}_y = \frac{\overline{SG_y}}{S} = \frac{1275.5\ lbm/h}{1.576\ ft^2} = 809\ \frac{lbm}{ft^2 h}$$

$$S = \pi\,(diam)^2/4 = \pi\left(\tfrac{17}{12}\ ft\right)^2/4 = 1.576\ ft^2$$

DIFFUSIVITIES AND SCHMIDT NUMBERS FOR GASES IN AIR† AT 25 °C AND 1 ATM

Gas	Volumetric diffusivity D_v, ft^2/h	$N_{Sc} = \frac{\mu}{\rho D_v}$‡
Acetic acid	0.413	1.24
Acetone	0.32§	1.60
Ammonia	0.836	0.61
Benzene	0.299	1.71
n-Butyl alcohol	0.273	1.88
Carbon dioxide	0.535	0.96
Carbon tetrachloride	0.26§	1.97
Chlorine	0.43§	1.19
Chlorobenzene	0.24§	2.13
Ethane	0.49§	1.04
Ethyl acetate	0.278	1.84
Ethyl alcohol	0.396	1.30
Ethyl ether	0.302	1.70
Hydrogen	2.37	0.22
Methane	0.74§	0.69
Methyl alcohol	0.515	1.00
Naphthalene	0.199	2.57
Nitrogen	0.70§	0.73
n-Octane	0.196	2.62
Oxygen	0.690	0.74
Phosgene	0.31§	1.65
Propane	0.36§	1.42
Sulfur dioxide	0.44§	1.16
Toluene	0.275	1.86
Water vapor	0.853	0.60

† By permission, from T. K. Sherwood and R. L. Pigford, *Absorption and Extraction*, 2nd ed., p. 20. Copyright 1952, McGraw-Hill Book Company, New York.
‡ The value of μ/ρ is that for pure air, 0.512 ft^2/h.
§ Calculated by Eq. (21.25).

TABLE 22.1
Characteristics of dumped tower packings[9,12b,21]

Type	Material	Nominal size, in.	Bulk density,† lb/ft³	Total area,† ft²/ft³	Porosity, ϵ	Packing factors‡ F_p	Packing factors‡ f_p
Raschig rings	Ceramic	½	55	112	0.64	580	1.52§
		1	42	58	0.74	155	1.36§
		1½	43	37	0.73	95	1.0
		2	41	28	0.74	65	0.92§
Pall rings	Metal	1	30	63	0.94	56	1.54
		1½	24	39	0.95	40	1.36
		2	22	31	0.96	27	1.09
	Plastic	1	5.5	63	0.90	55	1.36
		1½	4.5	39	0.91	40	1.18
Berl saddles	Ceramic	½	54	142	0.62	240	1.58§
		1	45	76	0.68	110	1.36§
		1½	40	46	0.71	65	1.07§
Intalox saddles	Ceramic	½	46	190	0.71	200	2.27
		1	42	78	0.73	92	1.54
		1½	39	59	0.76	52	1.18
		2	38	36	0.76	40	1.0
		3	36	28	0.79	22	0.64
Super Intalox saddles	Ceramic	1	—	—	—	60	1.54
		2	—	—	—	30	1.0
IMTP*	Metal	1	—	—	0.97	41	1.74
		1½	—	—	0.98	24	1.37
		2	—	—	0.98	18	1.19
Hy-Pak	Metal	1	19	54	0.96	45	1.54
		1½	—	—	—	29	1.36
		2	14	29	0.97	26	1.09

† Bulk density and total area are given per unit volume of column.

‡ Factor F_p is a pressure-drop factor and f_p a relative mass-transfer coefficient.

§ Based on NH_3-H_2O data; other factors based on CO_2-NaOH data.

$$H_y = 1.4\,ft \left(\frac{809}{500}\right)^{0.3} \left(\frac{1500}{165}\right)^{0.4} \left(\frac{1.86}{0.66}\right)^{\frac{1}{2}} \frac{1}{1.36}$$

$$= 4.8\,ft$$

slope of equil. curve $= 0.038$

$$H_{oy} = H_y + \frac{m}{(L/V)} H_x$$

$$= 4.8\,ft + \left(\frac{0.038}{0.0360}\right)(1.0\,ft)$$

$$= 5.9\,ft$$

(VI) Number of transfer units

$y_a = 0.00176?$

$y_a^* = (0.038)(0.01) = 0.0019$

$y_a - y_a^* = -0.000127$

$y_b = 0$

$y_b^* = (0.038)(0.001) = 0.000038$

$y_b - y_b^* = -0.000038$

$$L/V = \text{slope of op. line} \approx \frac{y_a - y_b}{x_a - x_b} = \frac{0.00176? - 0}{0.05 - 0.001}$$

$$= 0.0360$$

[or $(L/V)_a = 720/20035.71 = 0.03594$

$(L/V)_b = 684.685/20000 = 0.03423$

$\overline{(L/V)}$ = arithmetic mean = 0.0351 close]

$$\overline{(y-y^*)}_L = \frac{(y_1-y_1^*)-(y_2-y_2^*)}{\ln\left(\frac{y_1-y_1^*}{y_2-y_2^*}\right)}$$

$$= \frac{-0.000177-(-0.000018)}{\ln\left(\frac{-0.000177}{-0.000078}\right)} = -0.0000772$$

$$N_{oy} = \frac{y_2-y_1}{\overline{(y-y^*)}_L} = \frac{0-0.001763}{-0.0000772}$$

$$= 22.84$$

(viii) Packed height

$$Z_T = N_{oy} H_y = (22.84)(5.9 \text{ ft})$$

$$= \boxed{135 \text{ ft packed ht.}}$$