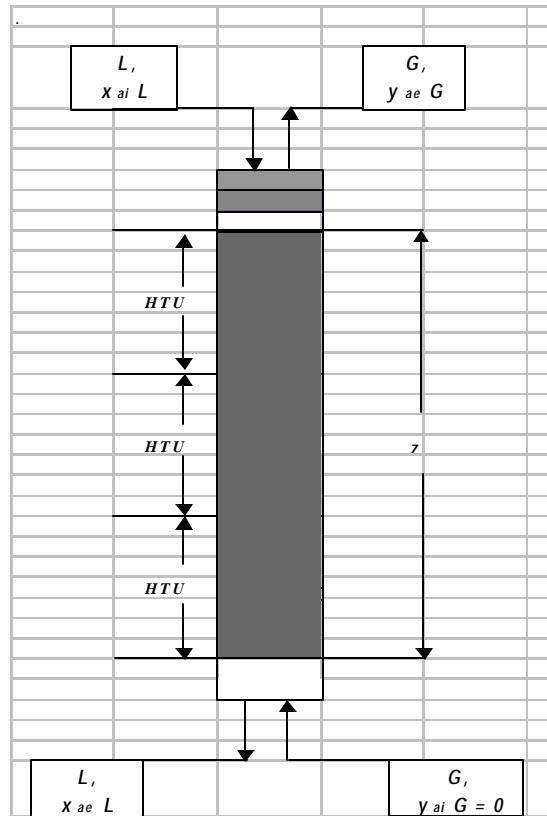


## APPENDIX D EXAMPLE AIR STRIPPING BY PACKED COLUMN



**Figure D-1. Random "dumped" packed tower.**

### D-1. Parameters.

$NTU$  = number of transferunits

$HTU$  = height of transfer unit[m]

$Z = NTU \times HTU$  packingdepth[m]

$L = \text{molarliquid(water)flow per unit of stripper cross-sectional area} \left[ \frac{\text{kg-mole}}{\text{m}^2 \text{ sec}} \right]$

$G = \text{molargas(air)flow per unit of stripper cross-sectional area} \left[ \frac{\text{kg-mole}}{\text{m}^2 \text{ sec}} \right]$

$x_{ai} = \text{molefraction of contaminant } a \text{ in liquid (water) influent} \left[ \frac{\text{kg-mole}}{\text{kg-mole water}} \right]$

$x_{ae}$  = molefraction of contaminant  $a$  in liquid(water) effluent  $\left[ \frac{\text{kg-mole}}{\text{kg-molewater}} \right]$

$y_{ai}$  = molefraction of contaminant  $a$  ingas(air)influent  $\left[ \frac{\text{kg-mole}}{\text{kg-moleair}} \right]$

$y_{ae}$  = molefraction of contaminant  $a$  ingas(air)effluent  $\left[ \frac{\text{kg-mole}}{\text{kg-moleair}} \right]$

$$(x_{ai} - x_{ae}) L = (y_{ae} - y_{ai}) G$$

which is moles of contaminant  $a$  transferred from liquid to gas per unit of stripper cross-sectional area per unit time (kg-mole/s)

$$\left( \frac{x_{ai} - x_{ae}}{y_{ae} - y_{ai}} \right) = \frac{G}{L} \left[ \frac{\text{kg-mole air}}{\text{kg-mole water}} \right]$$

which is the molar ration of gas (air) to liquid (water), and assumining uncontaminated influent air:

$$y_{ai} = 0$$

$$\frac{G}{L} = \left( \frac{x_{ai} - x_{ae}}{y_{ae}} \right)$$

where  $x_{ai}$  and  $L$  are field measurements and  $x_{ae}$  is imposed by ARAR, and

$p_{Te}$  = total pressure of gas (air) effluent (atm)

$P_{ae}$  = partial pressure of contaminant  $a$  in gas (air) effluent (atm).

From Dalton's Law of partial pressures:

$$y_{ae} = \frac{P_{ae}}{P_{Te}} \left[ \frac{\text{mole}}{\text{mole}} \right] \text{ or } \left[ \frac{\text{atm}}{\text{atm}} \right]$$

$$P_{ae} = y_{ae} P_{Te} \text{ [atm]}$$

at equilibrium from Henry's Law:

$$P_{ae} = H_a x_{ai} \text{ [atm]}$$

substituting yields:

$$y_{ae} p_{Te} = H_a x_{ai} \text{ [atm]}$$

$$y_{ae} = \frac{H_a x_{ai}}{p_{Te}} \text{ [atm]}$$

and from the material balance:

$$(x_{ai} - x_{ae}) \left( \frac{L}{G} \right) = y_{ae} \left[ \frac{\text{mole}}{\text{mole}} \right]$$

Again substituting gives

$$(x_{ai} - x_{ae}) \left( \frac{L}{G} \right) = \frac{H_a x_{ai}}{p_{Te}}$$

$$\frac{x_{ai} - x_{ae}}{x_{ai}} = \frac{H_a \left( \frac{G}{L} \right)}{p_{Te}}$$

The fraction of contaminant transferred from liquid (water) to gas (air) phase is:

$$\frac{C_{ai} - C_{ae}}{C_{ai}} = \frac{x_{ai} - x_{ae}}{x_{ai}}$$

where

$C_{ai}$  = concentration of contaminant  $a$  in liquid (water) influent [ $\mu\text{g/L}$ ]

$C_{ae}$  = concentration of contaminant  $a$  in liquid (water) effluent [ $\mu\text{g/L}$ ].

For convenience, the flows of water and air are measured volumetrically

$$C_{ai} (L) Q_L = C_{ae} (L) Q_L + C_{ae} (G) Q_G$$

and

$$\frac{C_{ai} - C_{ae}}{C_{ai}} = \left( \frac{H'_a}{p_{Te}} \right) \left( \frac{Q_G}{Q_L} \right)$$

where  $p_{Te}$  is measured as a fraction of the standard atmosphere (atm),  $H_a$  is the dimensionless Henry's constant  $H_a/C_0RT$ , actually (volume/volume),  $Q_g/Q_L$  is reduced to common flow units [ $m^3/m^3$ ], and  $C_0$  is the molar density of water at 20°C, 55.41 kg mole/ $m^3$ . The theoretical minimum, equilibrium, moles of gas required  $G_{min}/L$  is calculated from the influent and effluent concentrations and the “dimensionless” Henry’s constant ( $H_a$ ).

$$R_u = 0.08205746 \left[ \frac{m^3 \text{ atm}}{\text{kg-mole K}} \right] \text{ the universal gas constant}$$

At 1 atm and 20°C the molar density of water is  $C_0$ , 55.41 kg-mole/ $m^3$ .  $Q_g/Q_L$  [ $m^3/m^3$ ] is the air-to-water ratio,  $ATW$ .

$$y_{ae} = H_a x_{ai}/p_{Te} \text{ (mole/mole)}$$

Substituting gives

$$\frac{L(x_{ai} - x_{ae})}{G} = \frac{H_a x_{ai}}{p_{Te}}$$

and rearranging yields

$$\frac{G_{min}}{L} = \frac{(x_{ai} - x_{ae}) p_{Te}}{H_a x_{ai}}$$

which is the equilibrium molar ratio of gas (air) to liquid (water).

## **D-2. Develop the Design Basis.**

- a. Characterize the influent conditions and effluent requirements, including RI/FS data + total organics + background inorganics and minimum water temperature.

**Table D-1**  
**Contaminants**

<i>Contaminant</i>	<i>Formula</i>	<i>GMW*</i> [g/g-mole]	<i>CAS Number</i>	<i>H<sub>a</sub>**</i> [atm/mole/mole]
Benzene	C <sub>6</sub> H <sub>6</sub>	78.11	71-43-2	309.2
Toluene	C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	92.14	108-88-3	353.1
Trichloroethylene (TCE)	C <sub>2</sub> HCl <sub>3</sub>	131.50	79-01-6	506.1

\*The [gram] molecular weight of the contaminant.  
\*\* H<sub>a</sub> at 20°C (296.13 K).

b. Design the pumping system to maintain the flow. Use the real flow rate, not rounding up. Discharge head adjustments for the stripper are added to the TDH. The aggregate flow from the hydraulic barrier is 440 gpm (0.0278 m<sup>3</sup>/s) in this example.

c. Design the pre-treatment system to prevent scale/slime from clogging the stripper (if water is high in hardness, iron or manganese).

**Table D-2**  
**Background Inorganic Concentrations**

<i>Ion</i>	<i>mg/L</i>	<i>GMW</i>	<i>Valence</i>	<i>GEqW*</i>	<i>meq/L</i>	<i>mg/L as CaCO<sub>3</sub></i>
CO <sub>2</sub>	O	44	-2	22	0.00	0.00
<b>Anions</b>						
SO <sub>4</sub>	60	96	-2	48	1.25	62.46
Cl	54	35	-1	35	1.52	76.15
HCO <sub>3</sub>	30	61	-1	61	0.49	<u>24.58</u>
					TOTAL	163.19
CaCO <sub>3</sub>		100	0	50	0.00	0.00
<b>Cations</b>						
Na	10	23	1	23	0.43	21.75
Ca	40	40	2	20	2.00	99.80
Fe	0.3	56	2	28	0.01	0.54
Mg	10	24	2	12	0.82	41.12
Mn	0.05	55	2	27	0.00	<u>0.09</u>
					TOTAL	163.29

\* GEqW is the [gram] equivalent weight of the inorganic ion.

d. Construct a contaminant material balance for the stripping system.

**Table D-3**  
**Removal Requirements**

<i>Contaminant</i>	<i>Concentration</i> [mg/L]			<i>Mole Fraction</i> [mole/mole]	
	<i>Influent,</i> $C_{ai}$	<i>Effluent Standard,</i> $C_{ae}$	<i>Removal Requirement</i>	$x_{ai}$	$x_{ae}$
Total VOCs	2500	NA	NA	NA	NA
Benzene	750	10	98.7%	0.17330	0.00231
Toluene	1000	100	90.0%	0.19588	0.01959
Trichloroethylene (TCE)	750	100	86.7%	0.10294	0.01373

e. Assess the air pollution control requirements from the material balance and the regulations.

### **D-3. Determine the Column Diameter.**

a. Determine a preliminary stripper cross-sectional area for the sustained pumping rate, 440 gpm ( $0.02776 \text{ m}^3/\text{s}$ ) using 45 gpm/ft<sup>2</sup> ( $0.03056 \text{ m/s}$ ) for the stripper surface loading.

$$\begin{aligned}
 A &= \frac{Q \text{ ft}^2}{45 \text{ gpm}} \left( \frac{Q \text{ m}^2 \text{ s}}{0.03056 \text{ m}^3} \right) \\
 &= 0.0222 \frac{Q \text{ ft}^2}{\text{gpm}} \left( 32.72 Q \frac{\text{s}}{\text{m}} \right) \\
 &= 0.0222(440 \text{ gpm}) \frac{\text{ft}^2}{\text{gpm}} \left( 32.72 \left( 0.02776 \frac{\text{m}^3}{\text{s}} \right) \frac{\text{s}}{\text{m}} \right) \\
 &= 9.7778 \text{ ft}^2 \left( 0.9084 \text{ m}^2 \right)
 \end{aligned}$$

b. Divide the area by the number of strippers.

$$\begin{aligned}
 a &= \frac{A}{\#} \\
 &= \frac{9.7778}{2} \text{ ft}^2 \left( \frac{0.9084 \text{ m}^2}{2} \right) \\
 &= 4.889 \frac{\text{ft}^2}{\text{stripper}} \left( \frac{0.4542 \text{ m}^2}{\text{stripper}} \right)
 \end{aligned}$$

c. Divide  $a = \pi (d^2/4)$  the unit area by  $\pi$ , multiply by 4 and take the square root.

$$\begin{aligned}
 d &\approx \sqrt{\frac{4a}{\delta}} \\
 d &\approx \sqrt{\frac{4(4.889)}{\delta}} \left( \sqrt{\frac{4(0.4542)}{\delta}} \right) \\
 d &\approx \sqrt{6.22473} (\sqrt{0.5783}) \\
 d &\approx 2.5 \text{ ft } (0.762 \text{ m})
 \end{aligned}$$

d. Bracket the calculated diameter with the nearest standard diameters. In this example, a 2.5-ft (0.762-m) diameter column is standard for most manufacturers. The availability of standard metric sizes should be verified.

#### **D-4. Find a Suitable Packing.**

a. Find packings in the diameter range of roughly 5 to 10% of the stripper diameter. The rule of thumb is 1 in. of packing diameter per 1 ft of tower diameter; 2.5 in. (0.0635 m) packing is not standard for most manufacturers.

b. Reconsider the number of strippers if the packings and diameters don't correspond. Three 2-ft diameter strippers with 2-in. packing could be used in lieu of two 2.5-ft-diameter strippers.

b. Find the area of the standard diameter strippers.

$$\begin{aligned}
 a &= \delta \frac{d^2}{4} \\
 &= \frac{(2.5 \text{ ft} \delta)^2}{4} \left( \frac{(0.762 \text{ m})\delta^2}{4} \right) \\
 &= 4.908 \text{ ft}^2 (0.456 \text{ m}^2)
 \end{aligned}$$

d. Calculate the surface hydraulic loading  $Q/A$  and compare the loading with various packing manufacturers' recommendations.

$$\frac{Q_L}{A} = \frac{220 \text{ gpm}}{4.908 \text{ ft}^2} \left( \frac{0.01388 \frac{\text{m}^3}{\text{s}}}{0.456 \text{ m}^2} \right) \text{ per stripper}$$

$$V_L = 44.82 \frac{\text{gpm}}{\text{ft}^2} \left( 0.03044 \frac{\text{m}}{\text{s}} \right)$$

e. Adjust the system configuration to get the hydraulics within the recommended range.

**D-5. Calculate the Minimum Gas Flow.** Determine  $G_{\min}$  and the critical contaminant from the following relationship:

$$\frac{Q_{G_{\min}}}{Q_L} = \frac{(C_{ai} - C_{ae})}{H_a C_{ai}}$$

**Table D-4**  
**Critical Contaminant**

Contaminant	For $P_{te} = 1 \text{ atm}$ and $20^\circ\text{C}$ (296.13 K)		
	$\frac{(C_{ai} - C_{ae})}{C_{ai}}$	$H_a$	$\frac{Q_{G_{\min}}}{Q_L}$
Benzene	0.9867	0.2320	4.253 $\frac{\text{m}^3}{\text{m}^3}$
Toluene	0.9000	0.2649	3.397 $\frac{\text{m}^3}{\text{m}^3}$
Trichloroethylene (TCE)	0.8667	0.3797	2.283 $\frac{\text{m}^3}{\text{m}^3}$
<b>Critical Contaminant (Benzene)</b>			
$\frac{Q_{G_{\min}}}{Q_L}$	=	4.253 $\frac{\text{m}^3}{\text{m}^3}$	(maximum)

**D-6. Calculate the Mass Transfer Rate.** Use a model, if available, to confirm the results.

$$\frac{a_w}{a_t} = \frac{-1.45 \left( \frac{s_c}{S} \right)^{0.75} N_{Re}^{0.01} N_{Fr}^{-0.05} N_{We}^{0.2}}{\frac{1}{K_{LA}} + \frac{1}{H_a K_G a_w} + \frac{1}{K_L a_w}}$$

where

- $a_w$  = wetted surface area of the packing ( $\text{m}^2/\text{m}^3$ )
- $a_t$  = total surface area of the packing ( $\text{m}^3/\text{m}^2$ )
- $K_{LA}$  = overall mass transfer rate (m/s)
- $K_L$  = liquid phase mass transfer rate (m/s)
- $K_G$  = gas phase mass transfer rate (m/s).

a. Calculate the dimensionless numbers (<http://www.processassociates.com/process/dimen> gives a comprehensive listing and definitions of dimensionless numbers).

$$N_{Re} = \left( \frac{1}{a_t} \right) \frac{V_L r_L}{\mathbf{m}} \quad \text{Reynolds Number}$$

$$N_{Fr} = a_t \frac{V^2}{g_c} \quad \text{Froude Number}$$

$$N_{We} = \left( \frac{1}{a_t} \right) \frac{V_L^2 r_L}{g_c S} \quad \text{Weber Number}$$

$$N_{Sc} = \frac{\mathbf{m}_L}{r_L D_L} \quad \text{Schmidt Number}$$

$$g_c = 9.807 \frac{\text{m}}{\text{s}^2} \quad \text{gravitation constant}$$

b. Look up the properties of the liquid (water) at the minimum water temperature,  $T$  (Table D-5).

**Table D-5**  
**Water at 20°C (293.16 K)**

$s = 0.072764 \frac{N}{m} = \frac{kg}{s^2}$	liquid surfacetension
$\mu_L = 0.0010042 \frac{kg}{m s}$	liquid viscosity
$r_L = 998.20 \frac{kg}{m^3}$	liquid density

c. Look up the properties of the critical contaminant, benzene, at the minimum water temperature,  $T$ ,

$$D_L = 8.91 \times 10^{-10} \frac{m^2}{s} \quad \text{liquiddiffusivityof benzene at } 20^\circ\text{C (296.13 K)}$$

d. Obtain data from product literature (Table D-6).<sup>\*</sup>

**Table D-6**  
**Packing Characteristics**

$d_p = 0.0508 \text{ m}$	nominal diameter
$a_t = 157 \frac{m^2}{m^3}$	totalsurfacearea
$s_c = 0.033 \frac{kg}{s^2}$	criticalsurfacetension for polyethylenepacking
$c_f = 15$	packing factor

e. Liquid mass velocity is as follows.

---

\* Jaeger Tripacks 2-in. (50.8 mm) plastic media.

$$\begin{aligned}
 L &= \mathbf{r}_L \frac{\rho_L}{A} \left[ \frac{\text{kg}}{\text{m}^2 \text{s}} \right] \text{liquid mass velocity at } 0.01388 \frac{\text{m}^3}{\text{s}} \text{ with a nominal column diameter of } 0.76 \text{ m} \\
 &= 998.19 \times \left( \frac{0.01388}{0.45599} \right) \\
 &= 30.38 \frac{\text{kg}}{\text{m}^2 \text{s}}
 \end{aligned}$$

f. Calculate the Reynolds Number,  $N_{\text{Re}}$ .

$$\begin{aligned}
 N_{\text{Re}} &= \frac{V_L \mathbf{r}_L}{a_t \mathbf{m}_L} \text{ (Reynolds Number)} \\
 V_L &= 0.3043 \frac{\text{m}}{\text{s}} \text{ from Paragraph D-4d} \\
 \mathbf{r}_L &= 998.19 \frac{\text{kg}}{\text{m}^3} \\
 a_t &= 157 \frac{\text{m}^2}{\text{m}^3} \\
 \mathbf{m}_L &= 0.0010042 \frac{\text{kg}}{\text{m s}} \\
 N_{\text{Re}} &= \frac{0.3043 \times 998.19}{157 \times 0.0010042} \\
 &= 192.7 \\
 N_{\text{Re}}^{0.1} &= 1.692
 \end{aligned}$$

g. Calculate the Froude Number,  $N_{\text{Fr}}$ .

$$\begin{aligned}
 N_{\text{Fr}} &= \frac{a_t V_L^2}{g_c} \text{ (Froude Number)} \\
 &= \frac{157 \times (0.3043)^2}{9.807} \\
 &= 0.01483 \\
 N_{\text{FR}}^{-0.05} &= 1.234
 \end{aligned}$$

h. Calculate the Weber Number,  $N_{\text{We}}$ .

$$\begin{aligned}
 N_{We} &= \left( \frac{1}{a_t} \right) \frac{V_L^2 R_L}{g_c s} \quad (\text{Weber Number}) \\
 &= \left( \frac{1}{157} \right) \frac{(30.39)^2 \times 998.19}{9.807 \times 0.072764} \\
 &= 0.08094 \\
 N_{We}^{0.2} &= 0.6048
 \end{aligned}$$

i. Calculate the wetted area of the packing,  $a_w$  from the dimensionless relation:

$$\frac{a_w}{a_t} = 1 - \exp \left[ -1.45 \left( \frac{s_c}{s} \right)^{0.75} \left( N_{Re}^{0.1} N_{Fr}^{-0.05} N_{We}^{0.2} \right) \right]$$

$$\begin{aligned}
 N_{Re}^{0.1} N_{Fr}^{-0.05} N_{We}^{0.2} &= 1.692 \times 1.234 \times 0.6048 \\
 &= 1.263
 \end{aligned}$$

$$\begin{aligned}
 \left( \frac{s_c}{s} \right)^{0.75} &= \left( \frac{0.033}{0.0728} \right)^{0.75} \\
 &= (0.45352)^{0.75} \\
 &= 0.553
 \end{aligned}$$

j. Calculate the wetted surface area.

$$\begin{aligned}
 \frac{a_w}{a_t} &= 1 - \exp [-1.45(0.553 \times 1.263)] \\
 &= 1 - \exp(-1.0125) \\
 &= 1 - 0.3633 \\
 &= 63.67\% \\
 a_t &= 157 \frac{\text{m}^2}{\text{m}^3} \\
 a_w &= 63.67\% (157) \\
 a_w &= 99.96 \frac{\text{m}^2}{\text{m}^3}
 \end{aligned}$$

k. Calculate the liquid phase mass transfer coefficient, Onda  $K_L$  from the following relationship:

$$K_L \left( \frac{\mathbf{r}_L}{\mathbf{m}_L g_c} \right)^{\frac{1}{3}} = 0.0051 \left( \frac{V_L \mathbf{r}_L}{a_w \mathbf{m}_L} \right)^{\frac{2}{3}} \left( \frac{\mathbf{m}_L}{\mathbf{r}_L D_L} \right)^{-0.5} (a_t d_p)^{0.4}$$

$$\begin{aligned} \left( \frac{\mathbf{r}_L}{\mathbf{m}_L g_c} \right)^{\frac{1}{3}} &= \left[ \frac{998.19}{(0.0010042)(9.8066)} \right]^{\frac{1}{3}} \\ &= (101,361)^{1/3} \\ &= 46.63 \end{aligned}$$

$$\begin{aligned} \left( \frac{V_L \mathbf{r}_L}{a_w \mathbf{m}_L} \right)^{\frac{2}{3}} &= \left( \frac{0.3043 \times 998.19}{99.96 \times 0.0010042} \right)^{\frac{2}{3}} \\ &= (302.7)^{\frac{2}{3}} \\ &= 45.08 \end{aligned}$$

$$\begin{aligned} \left( \frac{\mathbf{m}_L}{\mathbf{r}_L D_L} \right)^{-0.5} &= \left[ \frac{0.0010042}{(998.19)(8.91 \times 10^{-10})} \right]^{-0.5} \\ &= (1129)^{-0.5} \\ &= 0.02976 \end{aligned}$$

$$\begin{aligned} (a_t d_p)^{0.4} &= (157 \times 0.0508)^{0.4} \\ &= (7.9756)^{0.4} \\ &= 2.2946 \end{aligned}$$

$$\begin{aligned} K_L \left( \frac{\mathbf{r}_L}{\mathbf{m}_L g_c} \right) &= 0.0051 \left( \frac{V_L \mathbf{r}_L}{a_w \mathbf{m}_L} \right)^{\frac{2}{3}} \left( \frac{\mathbf{m}_L}{\mathbf{r}_L D_L} \right)^{-0.5} (a_t d_p) \\ K_L &= \frac{0.0051 \times 45.08 \times 0.02976 \times 2.2946}{46.63} \\ K_L &= 0.0003367 \frac{\text{m}}{\text{s}} \end{aligned}$$

*l.* Calculate the gas phase mass transfer coefficient, Onda  $K_G$ , using a stripping factor ( $R$ ) between 2 and 5. Try  $R = 2.5$  if air pollution control is required,  $R = 4.5$  if it isn't.

$$\frac{K_G}{(a_t D_G)} = 5.23 \left( \frac{G}{a_t m_G} \right)^{0.7} \left( \frac{m_G}{r_G D_G} \right)^{\frac{1}{3}} (a_t d_p)^{-2.0}$$

*m.* Look up the properties of the gas (air) at the minimum water temperature,  $T$  (Table D-7).

**Table D-7**  
**Air at 20°C (293.16 K) and 1 atm**

$m_G$	=	$1.773 \times 10^{-5} \frac{\text{kg}}{\text{m s}}$	gas viscosity
$r_G$	=	$1.2046 \frac{\text{kg}}{\text{m}^3}$	gas density

*n.* Look up the properties of the critical contaminant, benzene, at the minimum water temperature,  $T$ .

$$D_G = 9.37 \times 10^{-6} \frac{\text{m}^2}{\text{s}} \quad \text{gas diffusivity (benzene in air at } 20^\circ\text{C, 1 atm})$$

*o.* Calculate the gas flow rate from the relationship:

$$\begin{aligned} \frac{Q_{G_{\min}}}{Q_L} &= \frac{(C_{ai} - C_{ae})}{H_a' C_{ai}} \\ &= 4.253 \text{ from Table D-4} \end{aligned}$$

$$V_L = 0.03044 \frac{\text{m}}{\text{s}}$$

$$V_{G_{\min}} = 4.2635 \times 0.03044$$

$$= 0.1297 \frac{\text{m}}{\text{s}}$$

$$\begin{aligned}
 R &= 3.5 \\
 V_G &= R \times V_{G_{\min}} \\
 V_G &= 3.5 \times 0.1297 \\
 &= 0.4531 \frac{\text{m}}{\text{s}} \\
 G &= V_G r_G \\
 &= 0.4531 \frac{\text{m}}{\text{s}} \times 1.2046 \frac{\text{kg}}{\text{m}^3} \\
 &= 0.5458 \frac{\text{kg}}{\text{s m}^2}
 \end{aligned}$$

p. See Table D-6 for packing characteristics,  $a_t$  and  $d_p$ .

$$\begin{aligned}
 \left( \frac{G}{a_t m} \right)^{0.7} &= \left( \frac{0.5458}{157 \times 1.773 \times 10^{-5}} \right)^{0.7} \\
 &= (196.06)^{0.7} && \text{Gas phase Reynolds number} \\
 &= 40.24
 \end{aligned}$$

$$\begin{aligned}
 \left( \frac{m}{r_G D_G} \right)^{\frac{1}{3}} &= \left( \frac{1.773 \times 10^{-5}}{1.2046 \times 9.37 \times 10^{-6}} \right)^{\frac{1}{3}} \\
 &= (1.571)^{\frac{1}{3}} && \text{Gas phase Schmidt number} \\
 &= 1.162
 \end{aligned}$$

$$\begin{aligned}
 (a_t d_p)^{-2.0} &= (157 \times 0.0508)^{-2.0} \\
 &= (7.976)^{-2.0} \\
 &= 0.01572
 \end{aligned}$$

$$\begin{aligned}
 a_t D_G &= 157 \times 9.37 \times 10^{-6} \\
 &= 0.001471 \frac{\text{m}}{\text{s}}
 \end{aligned}$$

$$\begin{aligned}\frac{K_G}{(a_t D_G)} &= 5.23 \times 40.24 \times 1.162 \times 0.157 \\ &= 3.846 \\ K_G &= 3.853 \times 0.00147 \\ &= 0.005658 \frac{\text{m}}{\text{s}}\end{aligned}$$

*q.* Calculate the overall mass transfer coefficient, Onda  $K_{LA}$ .

$$\begin{aligned}\frac{1}{K_{LA}} &= \frac{1}{H_a K_G a_w} + \frac{1}{K_L a_w} \\ &= \frac{1}{0.2320 \times 0.005658 \times 99.96} + \frac{1}{0.003367 \times 99.96} \\ &= 7.622 + 29.71 \\ &= 37.33 \\ K_{LA} &= 0.02679 \text{ s}^{-1}\end{aligned}$$

$$\begin{aligned}HTU &= \frac{V_L}{K_{LA}} \\ &= \frac{0.03044}{0.02679} \\ &= 1.136 \text{ m}\end{aligned}$$

*r.* Determine  $NTU$  for the selected  $R$ .

$$\begin{aligned}R &= \frac{G}{G_{\min}} \\ &= \frac{H_a}{P_{Te}} \times \frac{G}{L} \\ &= 3.5\end{aligned}$$

$$NTU = \left( \frac{R}{R-1} \right) \ln \left( \frac{\left[ \left( \frac{x_{ai}}{x_{ae}} \right) (R-1) \right] + 1}{R} \right)$$

$$\begin{aligned}
 NTU &= \left( \frac{3.5}{3.5 - 1} \right) \ln \left[ \frac{\left( \frac{750}{10} \right) (3.5 - 1)}{3.5} + 1 \right] \\
 &= \left( \frac{3.5}{2.5} \right) \ln \left( \frac{(75 \times 2.5) + 1}{R} \right) \\
 &= 1.4 \times \ln \left( \frac{187.5 + 1}{3.5} \right) \\
 &= 1.4 \times \ln \left( \frac{188.5}{3.5} \right) \\
 &= 1.4 \times \ln 53.86 \\
 &= 1.4 \times 3.99 \\
 &= 5.88
 \end{aligned}$$

$$\begin{aligned}
 Z &= NTU \times HTU \\
 &= 5.88 \times 3.07 \\
 &= 17.13 \text{m} \\
 \frac{A}{W} &= \frac{0.4132 \frac{\text{m}^3}{\text{s}} \text{ air}}{0.02776 \frac{\text{m}^3}{\text{s}} \text{ water}} \\
 \frac{A}{W} &= 14.89
 \end{aligned}$$

s. Calculate the system headlosses, including the packing, the stripper inlet, and the exit losses. Size equipment, including blowers and pumps. Verify that blower discharge pressure is less than the value that would cause flooding.

## D-7. Complete the Design.

a. The following drawings are required.

- (1) Site plans.
- (2) Profiles.
- (3) Layout drawings.

(4) Details.

b. Design Analysis should be done in accordance with ER 1110-345-700, *Design Analysis, Drawings, and Specifications*, containing the following:

(1) Narrative.

(2) Documentation.

(3) Description.

(4) Calculations.

(5) Computer print out with documentation.

c. Specifications should be done in accordance with ER 1110-1-8155, and the following United Facilities Guide Specifications

02150 Piping; Off-Gas.

02521 Water Wells.

11212 Pumps Water Vertical Turbine.

11215 Fans/Blowers/Pumps Off-Gas.

11220 Precipitation/Coagulation/Flocculation Water Treatment.

11242 Chemical Feed Systems.

11378 Thermal (Catalytic) Oxidation Systems.

13405 Process Control.

15200 Pipelines, Liquid Process Piping.

d. Cost Estimate should be done in accordance with ER 1110-3-1301, *Cost Engineering Policy Requirements for Hazardous, Toxic Radioactive Waste (HTRW) Remedial Action Cost Estimate*.

e. Draft O&M manual should include cleaning procedures, as well as the O&M of the mechanical equipment.