SIMPLIFIED PACHED TOWER DESIGN CALCULATION FOR THE REMOVEL OF VOC'S FROM CONTAMINATED WATER

Mohamed Ali El-Behlil[1], El-Gezawi Saed M [1] and Sabri A. Adma [2]

[1]Chemical Engineering department – Tripoli University
[2] Process Engineering department Eni Oil Company Tripoli

ABSTRACT

Packed columns or air stripping columns are widely used for the treatment and removal of Volatile Organic Chemicals (VOC's) or Synthetic Organic Chemicals (SOC's) contaminating ground or surface waters. The applications of such packed towers can be costly unless a proper design is considered. The proper design must take into consideration several parameters such as the influent concentration and the Maximum Contaminant Level (MCL) set up or targeted for legislation by the regulatory agencies, and the type and number of contaminants (aliphatic or aromatic) that may present in the contaminated water. Packed tower Aeration column (PTA) or air stripping columns are usually designed using the currently available analytical equations, the commercial and the manufacturer supplied
software, and the McCabe-Thiele graphical methods.
This work outlines a simplified design calculation procedure for the packed tower aeration system for the VOC removal from contaminated water. The VOC's investigated in this study are those that associated with the chemical and oil industries. Through this simplified procedure the Packed tower height, diameter, type packing, minimum air to water ratio, power requirements for the air blower are determined.

Keywords: Volatile Organic Chemicals, Packed Tower Aeration, Contaminated water.

1. INTRODUCTION

Volatile Organic Compounds (VOCs) are a class of chemical compounds that share two main properties: (1) they evaporate easily from water into the air and (2) they contain carbon. Low concentrations of VOCs in water can produce a sweet, pleasant odor that is easily detected. VOCs are associated with products such as gasoline, plastics, and adhesives, dry-cleaning fluids, refrigerants and paints. Biological sources of VOCs include trees, cows and termites (methane), and cultivation. Crude oil tanking can also release VOCs into the atmosphere.

Three types of treatments may be used to remove or reduce VOC levels in drinking water, either alone or in combination with one another. These are Granular activated carbon (GAC) filters, Distillation, and Packed tower aeration (PTA).

Granular activated carbon (GAC) filters may be used to reduce VOC levels in drinking water. Treatment success depends on a number of factors, including (1) the type and amount of contaminant, (2) the rate of water usage, and (3) the type of carbon being used. Carbon filters should be replaced according to the manufacturer's instructions, and water should be tested after a treatment system is in place to ensure the system is working properly. Filtration systems may either be installed at the faucet (for point-of-use treatment), or where water enters the home (point-of-entry treatment). Point-of-entry systems provide safe water for bathing and laundry, as well as for cooking and drinking, and are therefore preferred for treatment of VOCs.

Distillers can remove VOCs using gas vents, fractional columns, and/or GAC filters. A combination of these methods is typically more effective for removing or reducing VOC levels than one of these methods alone. To maintain distillation equipment, empty the boiling chamber at least once a week, and more often if the distiller is used constantly. Packed tower aeration (PTA) combines air with water to turn contaminants into vapor, which is either released into the atmosphere or treated and released. Pumps and blower motors should be serviced and air filters replaced, as needed, to ensure these systems operate effectively.

2. PREVIOUS WORKS

The proper design of stripping packed tower for VOC removal is affected by some important parameters such as the use of proper correlation for mass transfer coefficients and vapor-liquid equilibria. There are several papers in the literature dealing with this issue. Linek *et al* measured the volumetric mass transfer coefficients of six volatile organic compounds in a pilot plant column with both hydrophilized and non hydrophilized polypropylene pall ring (25 mm). They observed that the coefficients for hydrophilized packing were higher that the non hydrophilized ones by 65% on average. This was attributed to a better wet ability of hydrophilized packing by water. For design purpose, they used the correlation presented by Kavanaugh and Trussell to calculate the depth of column. They also evaluated the design procedure of the packed stripper for VOC removal and concluded that the differences between the removal efficiencies calculated by their procedure and those observed experimentally did not exceed 10%. Summer felt *et al* investigated CO2 removal from water reuse systems in packed towers considering the rate of chemical reaction in stripping process. A combination of theoretical and practical considerations relevant to carbon dioxide control in water has been studied in their investigation.

A typical application scheme for a stripping column is shown in the following schematic diagrams (1 & 2) for VOC removal from contaminated water:

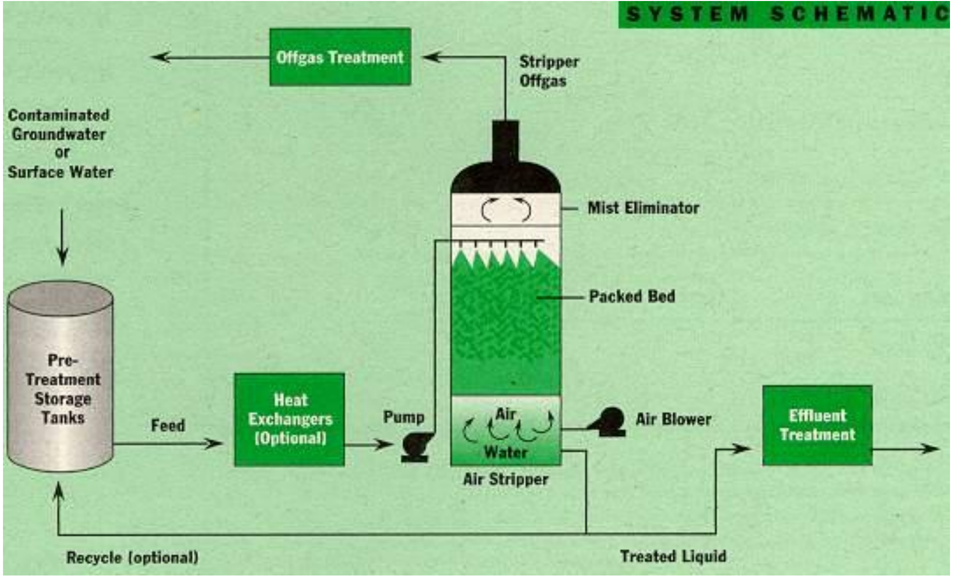


Fig (1) Schematic Diagram for a Packed Tower Aeration system used in the removal of VOC's from contaminated water.

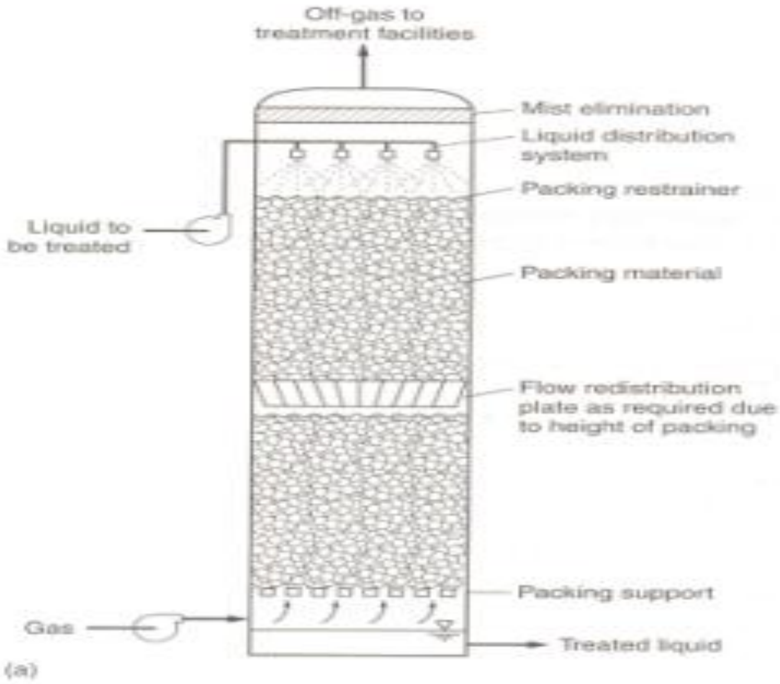


Figure (2) Counter current packed tower for VOC removal

When spilled or improperly disposed of, VOCs may be released into the environment. Any portion that does not evaporate may soak into the soil and can be carried into groundwater by rain, water and snow melt. The U.S. Environmental Protection Agency (EPA) estimates that VOCs are present in one-fifth of the nation’s water supplies._Packed tower aeration is usually considered to be the most cost effective process for removing volatile organic contaminants from the water. Capital costs, including the packing material, support for the packing material and the actual tower dominate total average costs for the construction and operating of this process. The energy requirements are virtually independent of flow, and influent VOC concentration. This is due to the fact that the air: to water ratio is the same for all of the towers (89.4). The model used to design the towers limits the variation in tower design and operation to tower size. A given Henry's constant will dictate the diameter of the tower and the required removal determines the tower height. Average costs increase with decreasing flow and with increasing concentrations of VOC's in the feed

Factors that influence the likelihood of contamination include:

1) Proximity of the well to the source of contamination. 2) The amount of VOCs that is spilled or discarded. 3) Depth of the well (shallow wells are affected by surface spills more quickly and more severely than deep wells). 4) Local geology (groundwater that is protected by thick, dense soils is less vulnerable to contamination). 5) Time (groundwater moves slowly, so it can take months or years after a spill before contamination reaches wells). The U.S. Environmental Protection Agency (EPA) has established maximum contaminant levels (MCLs) for the following VOCs:

Table (1) EPA National Primary Drinking Water Standards

VOC	**MCL**
Benzene	5 ppb
Toluene	1 ppm
Ethylbenzene	0.7 ppm
Xylene	10 ppm
Trichloroethylene	5 ppb

These Volatile Organic Chemicals are selected for this study, mainly because they were found to contaminate many drinking water scourers. Previous studies have found these chemicals to cause an adverse health effects even at a lower concentration levels. These VOC's can be removed effectively using packed tower aeration systems. In this study, mathematical model simulations will be conducted on each VOC at certain specified conditions. The degree of volatility represented by the Henry's law constant of each VOC plays a major role in the removal process. Henry's law constant was determined for each VOC using solubility data or correlation or any available experimental values. Table (2) summarizes the values of Henry's law constant for different units at two temperatures 10 ^{0}**C** and 25^{0}**C**.

Table (2) Henry's constant for some of VOCs

VOC	**H, dim 10 ^{0}C**	**H, atm 10 ^{0}C**	**H, atm m^{3}/ kgmole 10 ^{0}C**	**H, dim 25 ^{0}C**	**H, atm 25 ^{0}C**	**H, atm m^{3}/ kgmole 25 ^{0}C**
Benzene	0.115	148	2.67	0.221	302	5.40
Toluene	0.166	215	3.86	0.239	326	5.84
Ethylbenzene	0.211	273	4.90	0.275	375	6.72
O-Xylene	0.093	121	2.16	0.208	284	5.09
Trichloroethylene	0.244	316	5.67	0.542	740	13.25

3. MODEL ASSUMPTION

The following assumptions are made in the model description:

1. Heat of solution is negligible because the solution is too dilute. Therefore the enthalpy balance can be decoupled from the set of describing equations and the temperature can reasonably be assumed constant throughout the column.
2. Pressure drop throughout the column is negligible.
3. A linear vapor-liquid equilibria (Henry's law) is assumed.
4. Axial mixing is assumed to be negligible due to the high flow rate of stripping air.

4. ESTIMATING MODEL PARAMETERS

Equilibrium coefficients in the form of Henry's constants as a function of temperature were obtained from the literature. Mass transfer coefficients were estimated from Onda *etal* correlations. Other physiochemical properties such as diffusion coefficients, viscosity and density required in the model were calculated by the best well-known available correlations in the literature.

4.1 Description of mass transfer operations involving packed towers

Air stripping is the process of forcing air through polluted groundwater or surface water to remove harmful chemicals. The air causes the chemicals to change from a liquid to a gas (evaporate). The gas is then collected and cleaned. Air stripping is commonly used to treat ground-water as part of a pump and treat remedy.

Process consists of counter-current flow of water and air through a packing material. The packing material provides a high surface area for VOC transfer from the liquid to the gaseous phase. A wide variety of packing types are presently in use; several of these are shown in Figure (3). Although Raschig rings and Berl saddles were the most popular packing for many years, these have been largely replaced by higher capacity and more efficient packing, such as Pall rings, Intalox and Super Intalox saddles, and Flexipak. The Characteristics of dumped tower packing are shown on Table (3). The type of packing selected for a process depends on several factors. Desirable properties of the packing are:

Large void volume to decrease pressure drop,
Chemically inert to the fluids being processed.
Large surface area per unit volume of packing.
Light weight but strong.
Good distribution of fluids.
Good wet ability.

Tower packing are usually available in a variety of materials, including ceramic, metal, plastic, and carbon. In addition to desirable properties of packing, one limitation on the packing is the size be no greater than one-eighth of the tower diameter. If the size of the packing for particular tower is too large, a decrease in operating performance will result because channeling along the column wall.

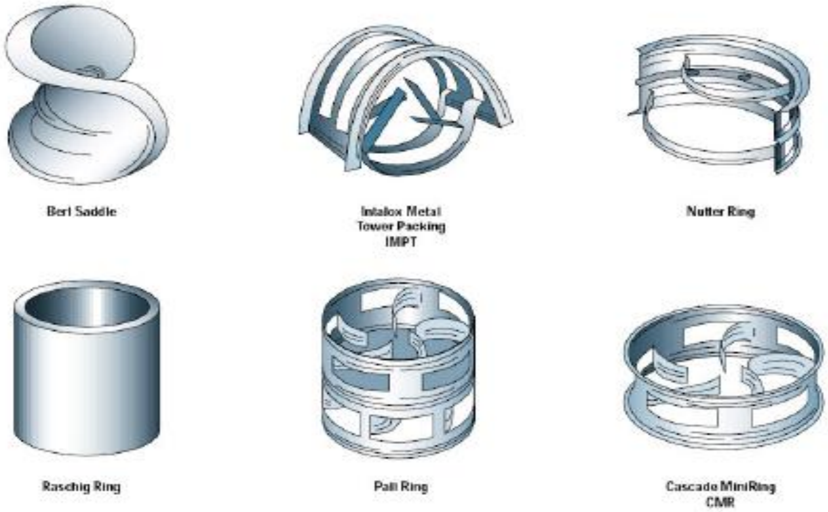


Figure (3) Typical Packing materials used in PTA systems for VOC removal

Table (3) Characteristics of dumped tower packing

Type	**Material**	**Nominal size, in.**	**Bulk density, lb/ft^3**	**Total area, ft^2/ft^3**	**Packing factor Fp, ft^{-1}**
Raschig rings	Ceramic	0.5	55	112	580
		1.0	42	58	155
		1.5	43	37	95
Hy-Pak	Metal	1.0	19	54	45
		2.0	14	29	26
Pall rings	Metal	1.0	30	63	56
		1.5	24	39	40
		2.0	22	31	27
Pall rings	Plastic	1	5.5	63	55
		1.5	4.8	39	40
Intalox saddles	Ceramic	0.5	46	190	200
		1	42	78	92
		1.5	39	39	52

Packed Tower Aeration Model Simulation equations

Summary of Equations and correlations for the design of packed-bed air stripping towers

Henry's Law $C = K_H \, ' \, C_L$ (1)

Van't Hoff's Relationship $\log K_H = -\Delta H^o/RT + k$

$K_H = \exp(A - B/T)$ (2)

Number of Transfer Units (NTU)

$$NTU = \left(\frac{S}{S-1}\right) \ln\left[\frac{(S-1)}{S}\frac{C_{L,in}}{C_{L,out}} + \frac{1}{S}\right] \quad (3)$$

Stripping Factor

$$S = K_H' \frac{Q_G}{Q_w} \tag{4}$$

Height of Transfer Units (HTU)

$$HTU = \frac{Q_w}{K_L aA} = \frac{L_M}{\rho_L K_L a} \tag{5}$$

Tower packing Height Z = HTU x NTU (6)

Pressure loss through packing support plate, demister, inlet and outlet duct

$$\Delta P = k_p (\frac{Q_G}{A_x})^2 \tag{7}$$

Blower Horsepower (HP/sq. ft of tower)

$$AirHP = \frac{144 Q_A (p_1 - p_2)}{33{,}000(E)} \tag{8}$$

Overall Mass Transfer, KL

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{k_G K_H^1} \tag{9}$$

One of the more common correlations to compute the k_G and k_L are the Onda's correlation

$$\frac{a_w}{a_t} = 1 - exp[-1.45(\frac{\sigma_C}{\sigma_L})^{0.75}(\frac{L_M^2}{a_t \mu_L})^{0.1}(\frac{L_M^2 a_t}{\rho_L^2 g})^{-0.05}(\frac{L_M^2}{\rho_L \sigma_L a_t})^{0.2}] \tag{10}$$

$$\frac{k_G}{a_t D_G} = 5.23[\frac{Q_M}{a_t \mu_G}]^{0.7}[\frac{\mu_G}{\rho_G D_G}]^{\frac{1}{3}}[a_t d_p]^{-2} \tag{11}$$

$$k_L [\frac{\rho_L}{\mu_L g}]^{1/3} = 0.0051[\frac{L_M}{a_w \mu_L}]^{2/3}[\frac{\mu_L}{\rho_L D_L}]^{-0.5}[a_t d_p]^{0.4} \tag{12}$$

Others include the Sherwood and Holloway correlation

$$\frac{k_L a}{D_L} = 10.764\alpha \left(\frac{0.3048 L_M}{\mu_L}\right)^{1-n} \left(\frac{\mu_L}{\rho_L D_L}\right)^{0.5} \tag{13}$$

Shulman et al. correlation

$$\frac{\kappa_L d_s}{D_L} = 25.1 \left(\frac{d_s L_M}{\mu_L}\right)^{0.45} \left(\frac{\mu_L}{\rho_L D_L}\right)^{0.5} \tag{14}$$

$$\frac{\rho_G k_G}{Q_M} = 1.195 \left(\frac{d_s Q_M}{\mu_G (1-\varepsilon)}\right)^{-0.36} \left(\frac{\mu_G}{\rho_G D_G}\right)^{0.667} \tag{15}$$

Effective surface area using Bravo and Fair correlation

$$\frac{a_e}{a_t} = 0.498 \left(\frac{\sigma_L^{0.5}}{Z^{0.4}}\right) \left[\left(\frac{\mu_L L_M}{\rho_L \sigma}\right)\left(\frac{6 Q_M}{a_t \mu_G}\right)\right]^{0.392} \tag{16}$$

Correlations for estimating the liquid and vapor phase diffusivites

Wilke and Chang Equation to estimate diffusivity of solute in liquid

$$\frac{D_{L,AB}\mu_B}{T} = \frac{7.48 x 10^{-8} (\phi_B M_B)^{1/2}}{V_b^{0.6}} \tag{A}$$

Hirschfelder, Bird and Spotz equation to estimate difusivity of solute in gas (nonpolar system)

$$D_{G,AB} = \frac{0.001858 T^{3/2} (\frac{1}{M_A} + \frac{1}{M_B})^{1/2}}{P \sigma_{AB}^2 \Omega_D} \tag{B}$$

σ can be estimated using the following equations

$$\sigma = 1.18 V_b^{1/3} = 0.841 V_c^{1/3} = 2.44 (\frac{T_c}{P_c})^{1/3}$$

(C)

Ω_D is a function of $\frac{\kappa T}{\varepsilon_{AB}}$, κ is the Boltzmann constant (1.38 x 10^{-16} ergs/K)

ε_{AB} = energy of molecular interaction (ergs), See Tables for values of Ω_D as a function of $\frac{\kappa T}{\varepsilon_{AB}}$, or estimated from the following regression equation

$$\Omega_D = 1.442 - 0.6915 \ln(\frac{\kappa T}{\varepsilon_{AB}}) + 0.2536 [\ln(\frac{\kappa T}{\varepsilon_{AB}})]^2 - 3.01 x 10^{-2} [\ln(\frac{\kappa T}{\varepsilon_{AB}})]^3 - 4.966 x 10^{-3} [\ln(\frac{\kappa T}{\varepsilon_{AB}})]^4$$

ε_A / κ can be estimated using the following equation, ε_A / κ = 0.77 T_c = 1.15 T_b

for a binary system $\sigma_{AB} = \frac{\sigma_A + \sigma_B}{2}$

$$\varepsilon_{AB} = \sqrt{\varepsilon_A \varepsilon_B} \quad , \quad \frac{\varepsilon_{AB}}{\kappa} = \sqrt{\frac{\varepsilon_A}{\kappa} \frac{\varepsilon_B}{\kappa}}$$

Air Stripping Tower Design procedure

1. Identify a target contaminant or select the contaminant whose final water quality standard is the most difficult to achieve (usually the least volatile contaminant).
2. Select removal efficiency needed.
3. Select the lowest water temperature and compute Henry's law constant for the contaminant using Equation (2).
4. Select airs to water (G/L) ratio - typical air to water ratios for groundwater are between 10 and 100. Compute the stripping factor S with Equation (4). Most designs used a stripping factor in the range **3 - 5**. However, **S** as high as 10 has been used.
5. Compute NTU from Equation (3).
6. Select a hydraulic loading rate and compute the cross-sectional area and the diameter of the tower. Hydraulic loading rates may vary between 5 and 50 gpm/ft^2 (3.4 x 10^{-3} to 0.034 m^3/m^2•s). Hydraulic loading rates between 20 to 35 gpm/ft^2 are usually used.
7. Select the packing material and the mass transfer correlations to be used - for example, Onda's correlation.
8. Compute the wetted surface area using Equation (10). The specific total packing area is usually obtained from the manufacturer, while the critical surface tension of the packing is assumed to be that of water. Several other pieces of information such as the density and viscosity of air and water, etc., can be obtained from standard textbooks or handbooks. Note that the equations use mass flux (kg/m^2•s).
9. If liquid and gas diffusivity of contaminant are not available, estimate the diffusivity of the contaminant in liquid and air phases with the Wilke and Chang equation and Hirschfelder, Bird, and Spotz equation, respectively .
10. With information from items 7 and 8 above, calculate the liquid and air phase mass transfer coefficients (kL and kG) from Equations (11) and (12).
11. The overall mass transfer KL is then computed using Equation (9). Compute HTU from Equation (5). Assume a = aw.
12. The height of the tower required is then computed from Equation 6. A safety factor can be added to the height of packing, if required.
13. Head losses through the packing itself can be estimated from manufacturers' literature or from Eckert's curve (see attached). The pressure drop across the demister packing support plate, duct work, and tower inlet and outlet is given by Equation 7. The pressure drop and gas flow rates can be calculated by applying the mathematical correlations and plots that were presented by Hines (et.al) ,and Trybal (et- al).
14. The value of **kp** in Equation (15) is approximately 0.093 ins H_2O-sec^2/ft^2) or 0.004 N-

s2/m4 in SI units for a full-scale tower. The total horsepower requirement can be estimated from Equation 8 where an assumed fan and motor efficiency of 50 and 70 percent, respectively, can be used to yield an overall efficiency of 35 percent.

15. The above procedure can be repeated, as required, for different air and liquid loading rates, packing materials, etc., to obtain the optimum design.

Strategies used in the model simulation:

1. Impact of the packed Tower pressure drop on the tower height.
2. Impact of the type and size of packing materials on the total power requirements and tower height.
3. Impact of the tower operating temperature on the tower dimensions (height and diameter).
4. Impact of air to water ratio on tower dimension and power requirements.

Model simulation results

All model simulation results that the impact of the design parameters air to water ratio, type and size of packing, and type of VOC on performance of the packed tower tabulated and plotted in the following section.

Table (4)

Effect of pressure drop on packed tower height for the removal of Toluene, ($C_0 = 1000$ µg/L, $C_e = 1$ µg/L, $Q_L = 0.02776$ m^3/sec , 0.5" ceramic raschig rings) at 20 ^{0}C and 1 atm

(V/Q)actual, m^3 air/ m^3 contaminated water	**Tower Height, m**		
	$\Delta P = 50$ N/m^2 /m	$\Delta P = 100$ N/m^2 /m	$\Delta P = 200$ N/m^2 /m
9.34	8.23	8.68	9.080
14.005	6.02	6.34	6.73
18.67	5.18	5.54	5.84
23.34	4.72	5.06	5.35
28.01	4.41	4.751	5.03
32.678	4.193	4.525	4.794
37.346	4.025	4.351	4.614
42.014	3.889	4.212	4.47
46.682	3.778	4.095	4.349

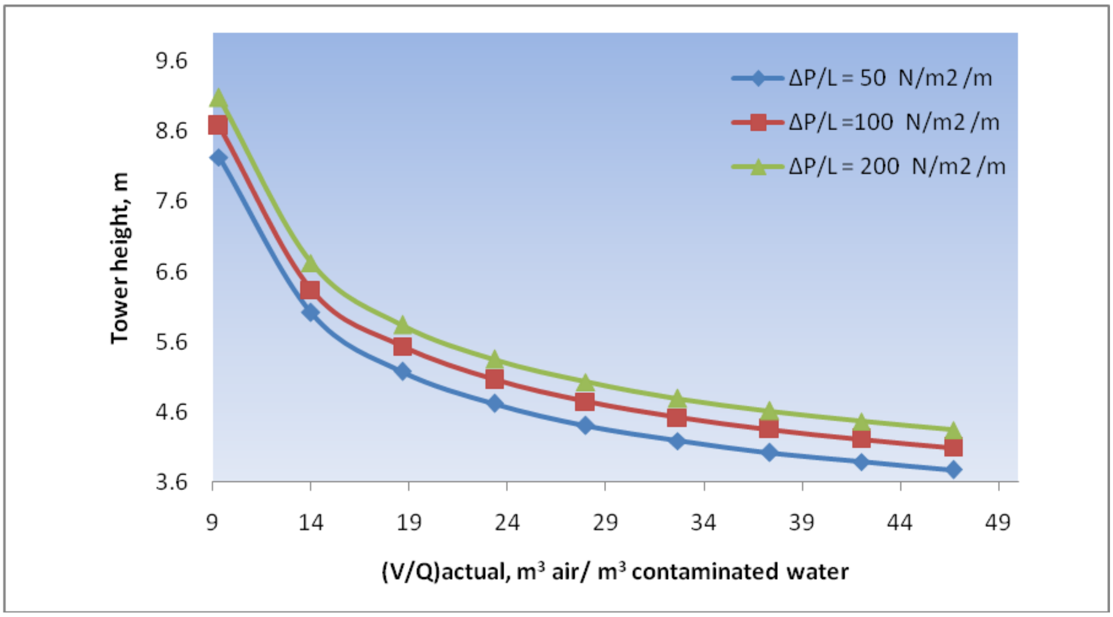


Figure (4)
Effect of pressure drop on height of packed tower for Toluene, (C_0 = 1000 µg/L, C_e = 1 µg/L, Q_L =0.02776 m^3/sec , 0.5" ceramic raschig rings) at 20 ^{0}C and 1 atm

Table (5)
Effect of packing size the Power requirement for Trichloroethylene (C_0 = 750 µg/L, Ce = 5 µg/L, Q_L =0.02776 m3/sec , ΔP/L = 50 N/m^2 /m) at 20 ^{0}C and 1 atm

$(V/Q)_{actual}$, m^3 air/ m^3 contaminated water	**Total power, kW**		
	0.5 " ceramic raschig rings	1" ceramic raschig rings	1.5 " ceramic raschig rings
5.06	2.084	2.983	3.757
7.592	1.601	2.266	2.835
10.123	1.430	2.012	2.504
12.653	1.345	1.884	2.339
15.184	1.298	1.811	2.243
17.715	1.268	1.766	2.185
20.245	1.250	1.741	2.149
22.776	1.242	1.724	2.128
25.307	1.237	1.717	2.117

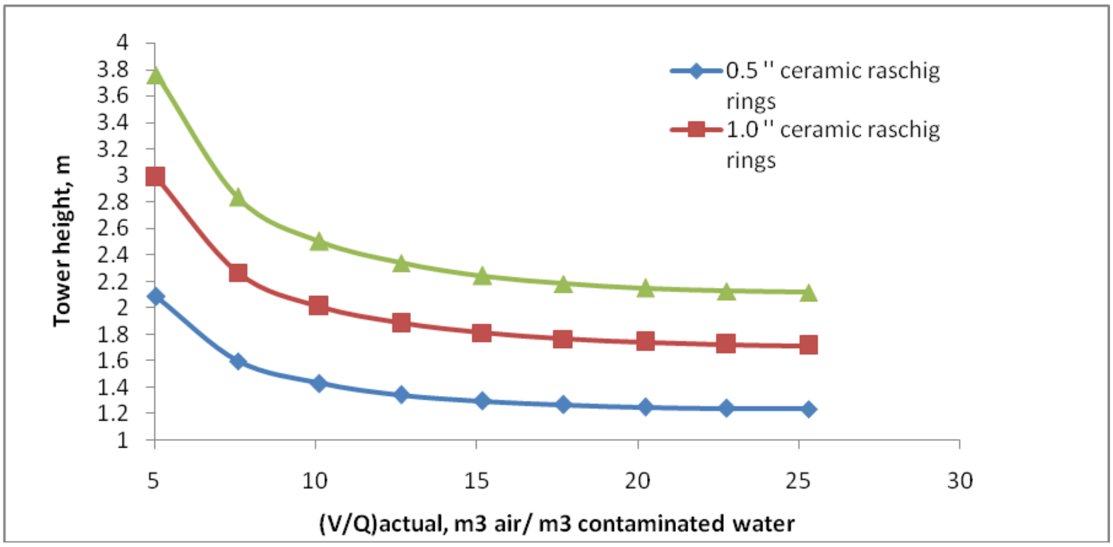


Figure (5)

Effect of packing diameter on the Power requirement for Trichloroethylene (C_0 = 750 μg/L, Ce = 5 μg/L, Q_L =0.02776 m^3/sec , ΔP/L = 50 N/m^2 /m) at 20 ^{0}C and 1 atm

Table (6)

Effect Operating tower temperature on Packed tower dimensions for Benzene($_{C0}$ = 750 μg/L, Ce = 5 μg/L, Q_L =0.02776 m^3/sec , ΔP/L = 100 N/m^2 /m, 1" metal Hypak) at 1 atm

(V/Q)	T = 10 ^{0}C		(V/Q)	T = 20 ^{0}C		(V/Q)	T = 25^{0}C	
	H, m	D, m		H, m	D, m		H, m	D, m
17.275	12.92	1.247	11.099	9.635	1.096	8.989	8.504	1.036
25.913	9.527	1.402	16.648	7.112	1.220	13.484	6.281	1.147
34.550	8.205	1.532	22.197	6.131	1.324	17.979	5.418	1.240
43.188	7.462	1.646	27.717	5.580	1.415	22.474	4.933	1.322
51.826	6.968	1.749	33.296	5.215	1.496	26.968	4.612	1.395
60.464	6.608	1.843	38.845	4.948	1.571	31.463	4.378	1.462
69.101	6.33	1.931	44.395	4.742	1.640	35.958	4.197	1.525
77.739	6.105	2.014	49.944	4.576	1.706	40.452	4.052	1.583
86.377	5.92	2.092	55.494	4.438	1.768	44.947	3.93	1.638

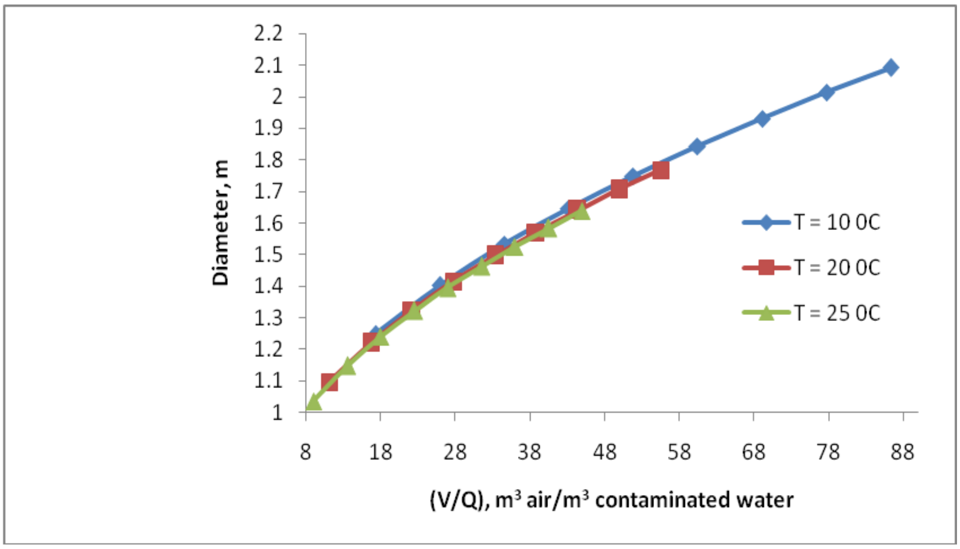


Figure (6.A)

Effect Operating tower temperature on Packed tower height for Benzene ($_{C0}$ = 750 µg/L, Ce = 5 µg/L, Q_L =0.02776 m^3/sec , ΔP/L = 100 N/m^2 /m, 1" metal Hypak) at 1 atm

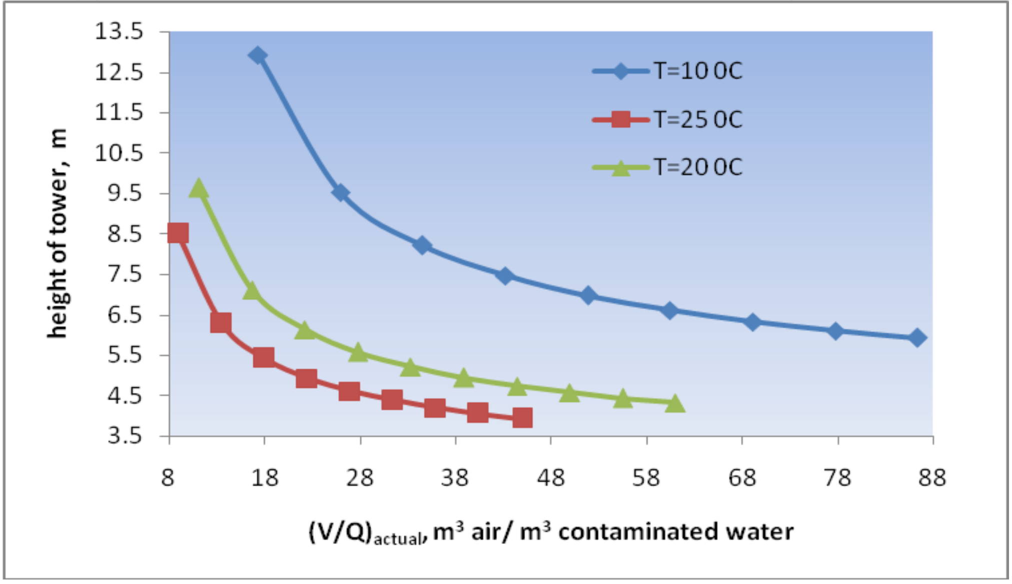


Figure (6.B)

Effect operating tower temperature on Packed tower height for Benzene ($_{C0}$ = 750 µg/L, Ce = 5 µg/L, Q_L =0.02776 m^3/sec , ΔP/L = 100 N/m^2 /m, 1" metal Hypak) at 1 atm

Table (7)

Effect air to water ratio on tower dimension and Power requirement (Trichloroethylene and Benzene, C_0 = 750 µg/L, C_e = 5 µg/L, Q_L =0.02776 m^3/sec , 1" metal hypak, ΔP/L = 100 N/m^2 /m) at 20 ^{0}C and 1 atm

(V/Q)actual, m^3 air/ m^3 contaminated water	Benzene	
	Height of tower, m	**Total power, kW**
11.099	9.635	5.147
16.648	7.112	3.415
22.197	6.131	3.253
27.747	5.58	3.243
33.296	5.215	3.342
38.485	4.948	3.458

Table (8)

Effect of air to water ratio on tower dimension and Power requirement (Trichloroethylene, C_0 = 750 µg/L, Ce = 5 µg/L, QL =0.02776 m^3/sec , 1" metal hypak, ΔP/L = 100 N/m^2 /m) at 20 ^{0}C and 1 atm)

(V/Q)actual, m^3 air/ m^3 contaminated water	Trichloroethylene	
	Height of tower, m	**Total power, kW**
5.061	10.429	3.961
7.592	7.785	3.112
10.123	6.760	2.857
12.653	6.185	2.751

15.184	5.804	2.714
17.715	5.527	2.713
20.245	5.311	2.734

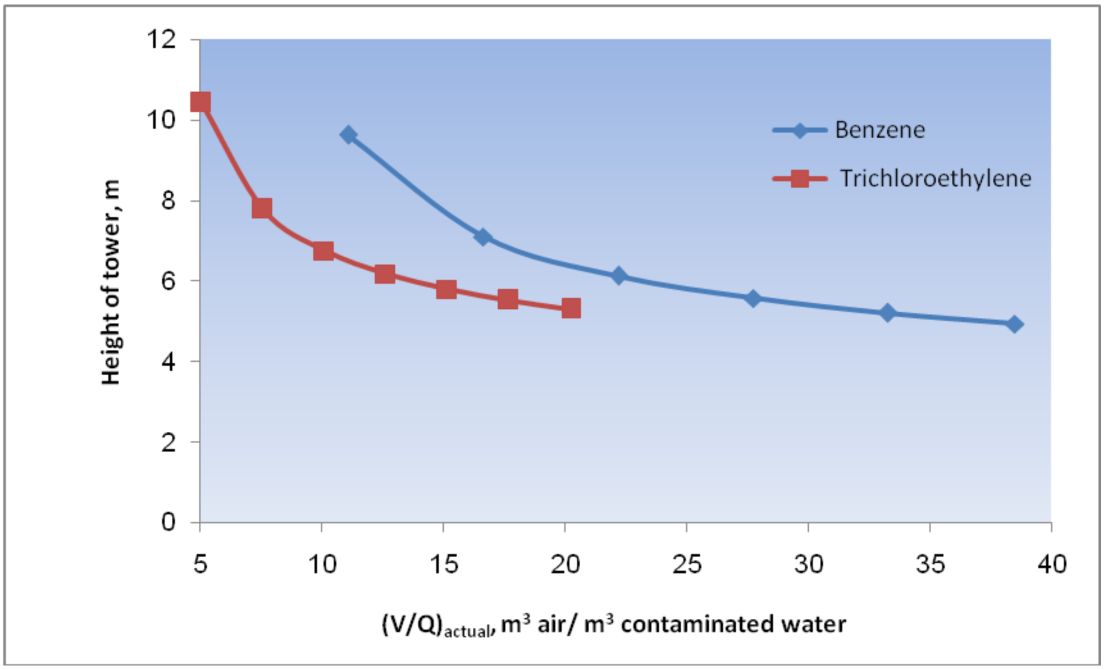


Figure (9.A)
Effect air to water ratio on tower height (Trichloroethylene and Benzene, C_0 = 750 µg/L, C_e = 5 µg/L, Q_L =0.02776 m^3/sec , 1" metal hypak, ΔP/L = 100 N/m^2 /m) at 20 ^{0}C and 1 atm

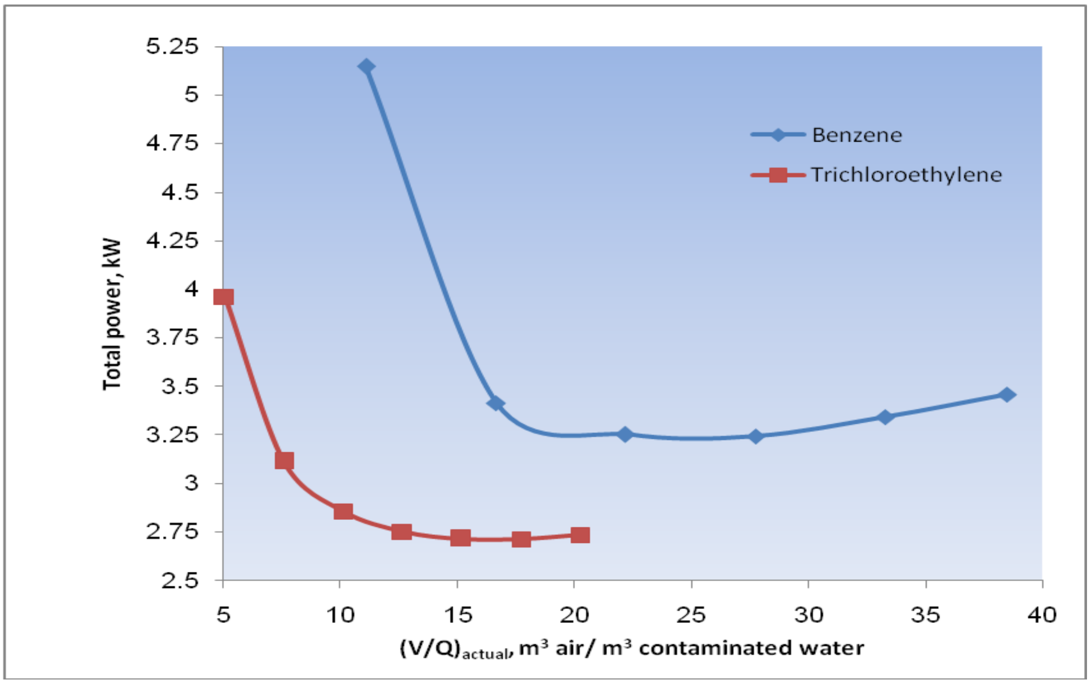


Figure (9.B)
Effect air to water ratio on power requirement (Trichloroethylene and Benzene, C_0 = 750 µg/L C_e = 5 µg/L, Q_L =0.02776 m^3/sec , 1" metal hypak, ΔP/L = 100 N/m^2 /m) at 20 ^{0}C and 1 atm

Table (9)

Effect different types of packing materials on the total volume of tower (Toluene, C_0 = 1000 µg/L, C_e = 1 µg/L, Q =0.02776 m^3/sec , ΔP/L = 200 N/m^2 /m) at 20 ^{0}C and 1 atm

(V/Q)actual, m^3 air/ m^3 contaminated water	**Total Volume ,** m^3		
	1" Ceramic Raschig Rings	1" Metal Hypak	1" Jaeger Tripacks plastic media
9.336	17.286	11.183	8.273
14.005	15.252	9.858	7.218
18.673	15.182	9.804	7.028
23.341	15.575	10.042	7.296
28.009	16.134	10.389	7.537

Table (10)

Effect different types of packing materials on the power requirements (Toluene, C_0 = 1000 µg/L, C_e = 1 µg/L, Q =0.02776 m^3/sec , ΔP/L = 200 N/m^2 /m) at 20 ^{0}C and 1 atm

(V/Q)actual, m^3 air/ m^3 contaminated water	**Total Power KW**		
	1" Ceramic Raschig Rings	1" Metal Hypak	1" Jaeger Tripacks plastic media
9.336	6.461	7.651	7.195
14.005	5.376	6.487	6.064
18.673	5.257	6.367	5.867
23.341	5.365	6.526	6.128
28.009	5.563	6.800	6.420

Figure (10.A)

Effect different types of packing materials on tower volume (Toluene, C_0 = 1000 µg/L, C_e = 1 µg/L, Q =0.02776 m^3/sec , ΔP/L = 200 N/m^2 /m) at 20 ^{0}C and 1 atm

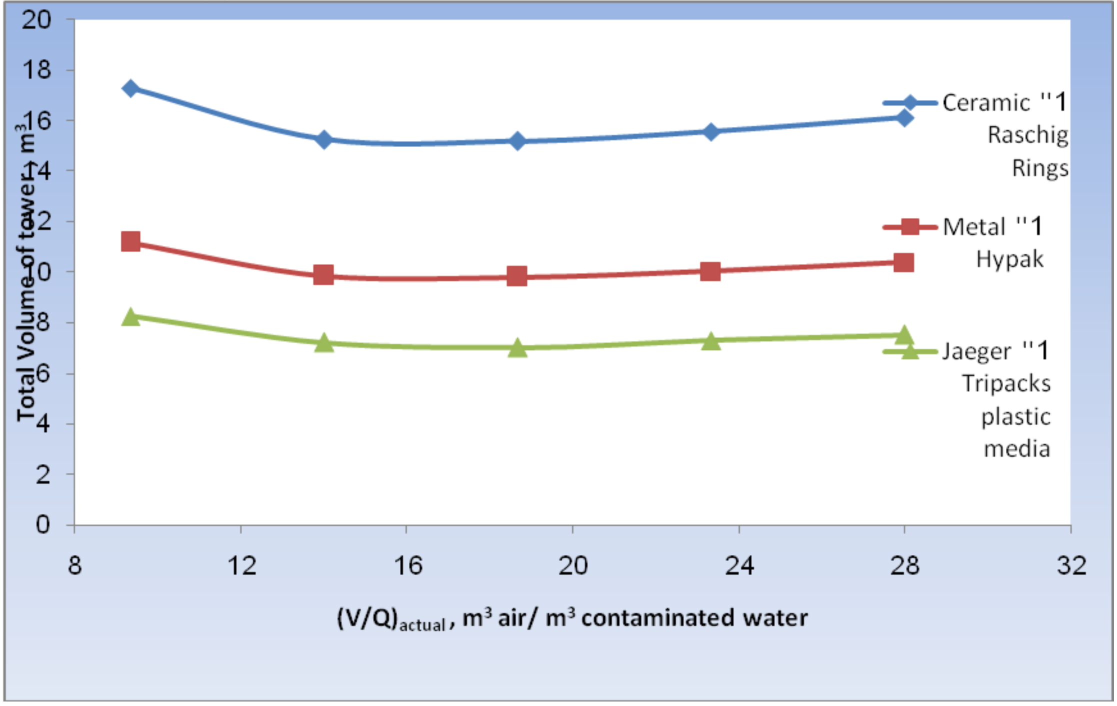
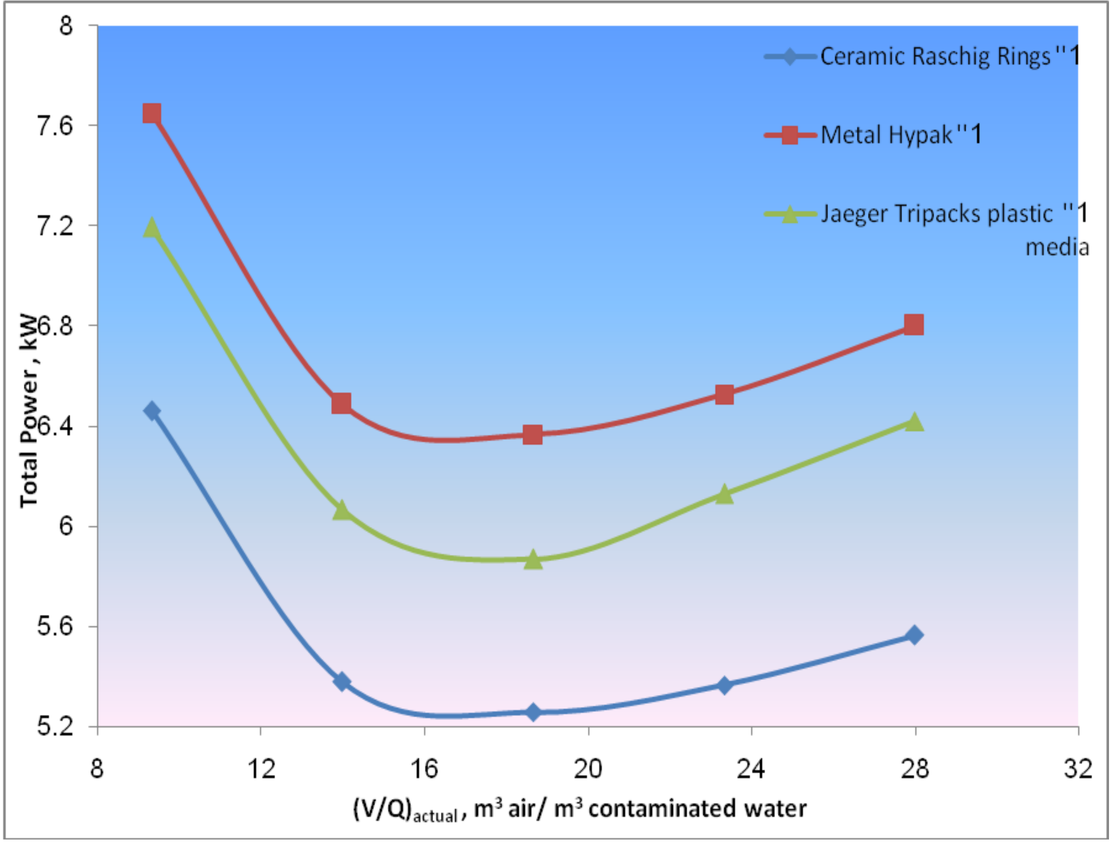


Figure (10.B)

Effect different types of packing materials on the power requirements (Toluene, C_0 = 1000 µg/L, C_e = 1 µg/L, Q =0.02776 m^3/sec , $\Delta P/L$ = 200 N/m^2 /m) at 20 ^{0}C and 1 atm



Discussion and Conclusion

The mathematical model used in this study can be considered a good and a quick design tool for packed towers used in the removal of volatile organic chemicals such as BTEX and TCE from contaminated water. The results obtained throughout this study need to be compared and verified with full scale packed towers. It is essentially to take into considerations the impact of in- organics that may present in the contaminate water particularly the iron and manganese, such metals are expected to cause some kind of fouling on the surface of the packing material and reduce the surface area available for mass transfer and ultimately reduce the removal efficiency. From the mathematical model simulations conducted in this study, the following conclusions were obtained:

1. The impact of the tower pressure drop on the tower dimensions was simulated at the specified conditions for the removal of Toluene at an influent concentration of (C0)= 1000 µg/L, and an effluent concentration (Ce) = 1 µg/L, assuming a liquid water flow rate (QL) =0.02776 m3/sec , 0.5" ceramic raschig rings) at 20 0C and 1 atm, The height of the tower was found to decrease as the air to water ratio increases at a fixed tower pressure drop. Also, for a constant air to water ratio, the tower height was found to increase slightly approximately 30 cm as the pressure drop increases.

2. The impact of the packing size and type on the total power requirements for Trichloroethylene at an influent concentration (C_0) = 750 µg/L, and effluent concentration (Ce) = 5 µg/L, assuming a liquid water flow rate (Q_L) =0.02776 m^3/sec, $\Delta P/L = 50$ N/m^2 /m) at 20ºC and 1 atm and using ceramic raschig rings. Model simulations have predicted that 0.5 inch ceramic raschig rings is the best packing size at the optimum value of the air to water ratio of 18.67 m^3 air/m^3 contaminated water because this size requires less energy than other sizes.
3. The impact of operating temperature on packed tower height for Benzene at an influent concentration (C_0) = 750 µg/L, and effluent concentration (Ce) = 5 µg/L, assuming a liquid water flow rate (Q_L) =0.02776 m^3/sec, $\Delta P/L = 100$ N/m^2 /m) at 20ºC and 1 atm using 1 inch metal Hypak . For any specified air to water ratio the tower height will decrease by increasing the temperature. While the impact of operating temperature on packed tower diameter for Benzene. The tower diameter will be decreasing by increasing the operating temperature regardless of the air to water ratio applied, and diameter was found to be in the range (1-2.1) meters.
4. The impact of air to water ratio on power requirement for the removal of either Trichloroethylene or Benzene at an influent concentration (C_0) = 750 µg/L, and effluent concentration (Ce) = 5 µg/L, assuming a liquid water flow rate (Q_L) =0.02776 m^3/sec, $\Delta P/L = 100$ N/m^2 /m) at 20ºC and 1 atm using 1 inch metal Hypak. Both VOCs can be effectively at these conditions using a packed tower with an approximate height of six meters at an optimum air to water ratio of 20 m^3 air/m^3 contaminated water.

5. The impact of the type of packing on the removal of Toluene can be best achieved at an optimum value of air to water ratio of 18.673 m^3 air/m^3 contaminated water and 1 inch ceramic raschig rings. .

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