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Modeling Tool for Air Stripping and Carbon Adsorbers to Remove Trace Organic Contaminants

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Abstract

Removal of trace organic contaminants from aqueous solutions by air strippers (AS) and fixed bed carbon adsorper (FBCA) has been studied. A trace organic treatment tool has been developed to capture and adapt the best-known design procedures and to have all regulated trace organics, their physical and chemical properties, and the corresponding maximum concentration limits. Outputs include the selected treatment method and the final design parameters of air stripper or fixed bed carbon adsorber. Running the model shows that water temperature is a very important factor in designing AS and FBA. It also shows that the best air pressure values, in AS, ranged between 150 -200 ATM. And there is a big relation between the column size and the packing material. On the other hand, it shows that FBA diameter has an obvious effect on the needed volume, and the best values ranged between 1.2 – 2.5 m.

Keywords*: Modeling, Air Stripper, Fixed Bed Adsorber, Trace Organics, Packing Materials.*

1. Introduction

Wells and surface dams are the most drinking water resources for many communities in the Middle East. Due to some agricultural and industrial practices trace organic contaminants (concentrations less than 1 mg/L) in pesticides, herbicides, fertilizers, and fuel stations may leach into these water resources. Many of these organic contaminants are regulated by, e.g., the U.S. Environmental Protection Agency (EPA) among other agencies due to their severe adverse effects on public health and the environment. An organic compound refers to that it contains carbon. The removal of such trace organic contaminants is not fully developed in some cases when stringent effluent standards are needed and a complex array of contaminants is present.

Organic compounds can be divided into natural and man-made contaminants. Man-made organic substances, sometimes called synthetic organic chemicals (SOCs), may reach and pollute water resources supply as a result of leaching from gasoline tanks and landfills, runoff of herbicides and pesticides, or from industrial wastes. Natural organics include matter derived from a living organism, plant or animal, and occur as a result of byproducts or biodegradation of plant and animal matter. The SOCs commonly include all pesticides, solvents, and household products. SOCs that are capable of vaporizing at relatively low temperature are called volatile organic chemicals (VOCs). These are generally treated with air stripping or granular activated carbon (GAC) [1-2]. Air stripping is one of the most effective technologies for removing (VOCs) [3]. The removal efficiency may reach 95–99%. However, releasing VOCs from air stripper into the atmosphere limits practical use [1]. The following is some examples of VOCs: phenolics, phthalate esters, naphthalenes, monocyclic aromatic hydrocarbons, polycyclic aromatic hydrocarbons, halogenated ethers, polychlorinated biphenyls (PCB's), nitrogenous organics, halogenated aliphatic hydrocarbons, and organochloride pesticides. When these organics occur at small concentrations in water they may be called trace organics. The physical and chemical properties of these contaminants are very important in choosing treatment method. These properties give an indication about the physical state of the compound and its mobility through soil and aquifer material and where it will tend to accumulate. These properties include: molecular weight, melting point, boiling point, vapor pressure, water solubility, specific gravity, liquid surface tension, liquid-water interfacial tension, and Henry's constant.

Fixed bed adsorbers (FBA) are tanks that contain material with high adsorption capacity in order to remove contaminants from water. Some activated carbon beds are made from raw materials such as wood, coal, or petroleum. In their experiments Tan et al have prepared activated carbon from oil palm shell, which was feasible to remove 2,4,6-trichlorophenol[4]. Olive waste cakes were shown to be a suitable precursor for the manufacture of activated carbon through chemical activation with phosphoric acid [5].

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Moreover, vetiver roots were used as raw materials for the production of activated carbon using steam and H3PO4 as activation agents [6].
The activated carbon bed's efficiency depends on the surface area, which ranges between 500 and 2000 m^2/g. However, the activated carbon's characteristics (hardness, density, pore and particle sizes, surface areas, extractable, ash, and PH) depend on the raw materials itself. However, few are known which can be used to characterize activated carbons and thus discriminate between different samples of carbon [7]. It is also possibleto prepare different proportions of micro-, meso-, and macropores. These properties decide which activated carbon is better for a specific application. For organic removal, Coagulation is needed for increasing adsorption efficiency [8].
There are two types of activated carbon: 1) powdered activated carbon (PAC), and 2) granular activated carbon (GAC). PAC is often applied at, or before, the coagulation/flocculation step.
The powdered carbon adsorbs contaminants and natural organic matter (NOM) that will be removed in the sedimentation and filtration processes and it is most often used for SOC or taste and odor control. Fig. 1 presents the mechanisms of adsorbates diffusion into the adsorbent, GAC, which has two parts: surface and pore diffusions [9-10].

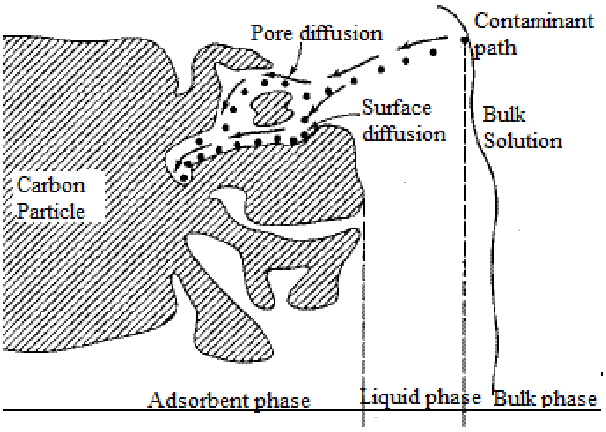

Fig. 1. Adsorption Mechanisms onto GAC [10].

AIR STRIPPER; transferring of volatile contaminants from water to air is called air stripping. Air stripping can be conducted by aeration tanks or packed towers. Both methods use pumped air to remove contaminants from water. The contaminated air is then collected and either vented into the atmosphere or routed to another treatment system depending on the contamination level. In the packed tower, contaminated water is distributed over packing materials and then the decontaminated water is collected from the bottom of the tower. Air is pumped countercurrent the water flow using fans before it is released to the surrounding areas with or without treatment. Stripping efficiency is very much affected by Henry's constant, which depends on temperature, is used to determine the rate of transfer from water into the air. Therefore, Henry's constant is an important design parameter that should be considered for the design of packed towers. Hence, when applying Henry's Law the mole fraction in liquid is proportional to the mole fraction in air at equilibrium (Fig. 2), which can be described by the following equation:

$$L_{out} \cdot x_{out} + G_{out} \cdot y_{out} = L_{in} \cdot x_{in} + G_{in} \cdot y_{in} \quad (1)$$

where G = gas flux, L = water flow, x = contaminant concentration in the water, and y = contaminant concentration in air.

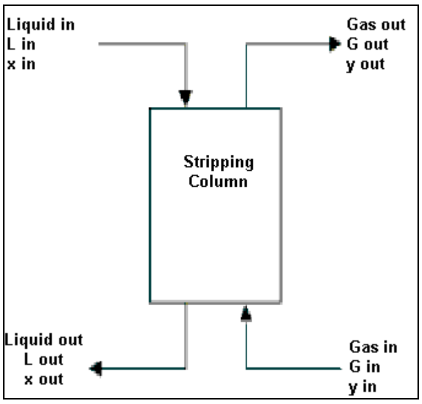

Fig. 2. Stripping column state

Packed towers can also be used for wastewater treatment. In [11] the authors found that 45% of the COD can be removed by packed tower. The removal efficiency of the packed tower depends on the air to water flow rate ratio, the mass transfer coefficient and the water temperature. Higher values of evaporation rate of the solvent in comparison with the rate of organic compound decrease organic removal from oily wastewater at temperature above 330K [12]. Hence, the major design parameters for designing packed stripper towers include: air to water ratio, hydraulic loading rates, packing material, size depth and diameter, gas pressure drop, and Henry's constant of the contaminant. The air to water ratio (A/W) of VOCs depends on the Henry's constant and the hydraulic stability of the column. Typically an air to water ratio (A/W) will range from 10:1 to 30:1. The A/W ratio is related to the stripping factor R, and the Henry's constant H by the following equation [13]:

$$R = 0.00075\ H\ (A/W) \quad (2)$$

Hydraulic loading rates defer from contaminant to another but can be defined experimentally. Increasing the contact surface area of the packing material will increase the stripping efficiency. Moreover, the resistance to airflow should be taken into consideration when selecting the packing material. The tower diameter and pressure drop for the packed tower can be estimated using pressure drop curves as developed by Eckert [14]. The curves relate pressure drop to gas and liquid loading rates (Fig. 3).

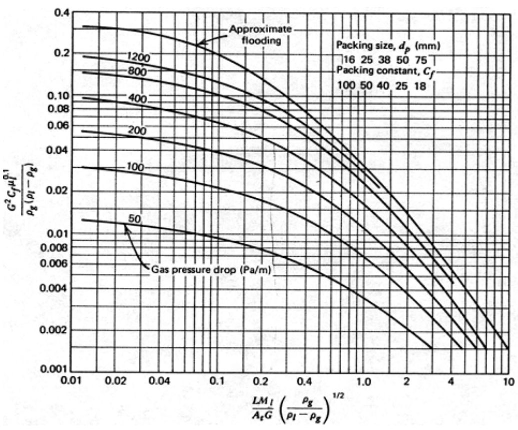

Fig. 3. Flooding and pressure drop correlations for packed towers [14].

where G: gas flux (kg/s/m^2), L: liquid flow (kmol/s), Ml: liquid molecular weight (g/mol), At: column area (m^2), rl: liquid density (kg/m^3), rg: gas density (kg/m^3), and Cf: packing factor.

The United State Environmental Protection Agency (USEPA) uses the following equation to calculate Henry's constant:

$$LnK_H = \frac{-\Delta H}{R^{`}.T} + \frac{\Delta So}{R^{`}} \quad (3)$$

where K_H : Henry's constant (atm : 1 atm = 101 325 Pa), ΔSo : entropy for organic compounds in the ideal-gas standard state (KJ/Kmol.V), R`: universal gas constant (1.987 kcal/g.kmole = 8.3136 KJ/Kmol.g), T: absolute temperature (oK), and ΔH: change in enthalpy due to dissolution of a component in a water (kcal/kmole). The change in enthalpy at the specific temperature can be calculated by Waston Correlation [15] knowing a reference value according to:

$$\frac{\Delta H_2}{\Delta H_1} = \left(\frac{1-Tr_2}{1-Tr_1}\right)^{0.38} \quad (4)$$

$$Tr_1 = T_b/T_c \quad (5)$$

$$Tr_2 = T_2/T_c \quad (6)$$

where Tb = boiling temperature (oK), Tc = critical temperature (oK), ΔH1 and ΔH2 are the heats of
vaporization at reduced temperature of Tr1, Tr2 respectively.
Entropy ΔSo can be calculated by the
following equation:

$$\Delta So = \frac{\Delta H^o - \Delta G^o}{T} \quad (7)$$

where ΔH^o : enthalpy of formation (kJ/Kmol), ΔG^o : Gibbs energy change of formation (KJ/Kmol). ΔHo, ΔGo, Tb, and Tc are tabulated in [16] for most contaminants that found in water.

Modeling water treatment method has taken much consideration, by companies, in last decades, while many researchers have worked on prepared models, the Swedish Water & Wastewater Association has developed The QMRA modeling tool to investigate a probably waterborne outbreak of calicivirus that occurred in the municipality of Lilla Edet, Sweden, after a period with heavy rain [17]. Elias et al have developed a helpful tool for that working with anaerobic biological reactors in order to optimize production of methane and the quality of the treated wastewaters [18]. Some air stripper suppliers have developed on line models for designing air stripper [19], Zhang and Cheng [20], on the other hand developed Mathematical model to describe the removal of cyanogen chloride from a gas stream passing through a bed packed with activated carbon impregnated with copper, chromium and silver. Lee et al have developed a model to predicting the performance of fixed-bed adsorbers [21].

The main objective of this paper is to develop a trace organic treatment model TOTM which will be achieved by: 1) Preparing lists of all regulated trace organic contaminants including the maximum allowable concentration levels (MCL) and some of their physical and chemical properties, 2) Reviewing and adapting the best available analysis and design procedures for the use of countercurrent packed towers for stripping VOCs from aqueous solutions, 3) Review and adapt the available analysis and design procedures for the use of fixed bed GAC adsorbers for adsorbing trace contaminants from aqueous solutions, 4) Develop a computer model which can be critiqued by experts or users and designs countercurrent packed towers and GAC fixed bed adsorbers based on the procedures adapted in steps (2), and (3), and 5) Use of the developed model as a decision-maker for choosing the treatment method and for final design.

2. Methodology

The following steps have been conducted in order to achieve the above objective: 1) A list of almost all trace organic contaminants that may occur in groundwater with their physical and chemical properties, and allowable Maximum Concentration Levels (MCLs), based on the U.S. Environmental Protection Agency (EPA) recommendations was prepared. Also, most available packing material with relevant properties was prepared. An air stripper's design model depending on Onda correlations was then developed. 2) Visual basic was used to build the model, which captures the expertise and the knowledge base outlined above. The model was developed to be easy to use and to lead the user by friendly windows to all possibilities of contaminant characteristics, initial concentrations, final concentrations, and method of treatment. This software gives the user properties of contaminants and available packing materials. The developed model was used to investigate the effect of temperature and packing material on air stripper volume.

2.1. Design protocol for fixed bed carbon absorbers

The design process was divided into many steps in order to simplify the design process depending on the Homogeneous Surface Diffusion Model (HSDM), which is an experimental model that includes the effects of external mass transfer, unsteady state intra- particle diffusion in the particle and a nonlinear adsorption isotherm [22]. Design equations are usually empirical and need many design parameters, which can be experimentally evaluated.
Adsorption Characteristics (K_f and 1/n): The Freundlich Isotherm constants (K_f and 1/n) in this paper are given data. However, they can be computed using the following equation by plotting the isotherm data on logarithmic scale, K_f is the intercept and 1/n is the slope.

$$q_e = k_f \, C_e^{1/n} \quad (8)$$

Mass Transfer Characteristics:
Diffusion coefficient Ds: Determining diffusion coefficient is vital for designing a fixed bed adsorber [9]. At first we have to calculate the dimensionless time and concentration data (C' and t', respectively) by: Equations. (9), (10), and (11) [10].

$$(C^{'}(t^{'}) = (C(t) - Ce)/ (Co - Ce) \quad (9)$$

$$\ln(t^{'}) = -1.9 - 9.16{*}C + 12.9{*}C^2 - 11.62 * C^3 \quad (10)$$

$$Ds = t^{'} {*}R^2 /t \quad (11)$$

Where: $t^{'}$: dimensionless time, $C^{'}$: dimensionless concentration, t : elapsed time (sec), R : mean radius of adsorbent particles in cm, and Ds: diffusion coefficient (cm^2/sec).
Evaluation of the precision of Ds: The average value of Ds will be obtained with various percentages of Ds (75%, 90%, 110%, and 125%). The model calculate values for $C^{'}$ by first calculating $t^{'}$ from the Ds value [10].

$$t' = t*Ds/R^2 \quad (12)$$

$$C' = -0.14 – 0.06*(\ln t') + 0.039*(\ln t')^2 + 0.0039*(\ln t')^3 \quad (13)$$

For each set of t' values, the average standard deviation for calculated values of C' and C' data will be obtained from the following equation [10]:

$$S^2 = \frac{\sum(C'_{data} - C'_{\text{mod elcalculated}})^2}{n-1} \quad (14)$$

Where: S^2 : average sum of the squares of residuals, S : standard deviation.

Then plot S^2 against Ds to evaluate the precision of the Ds determination. The Ds value corresponding to the minimum S is considered to be the best-fit value.

Liquid-phase mass transfer coefficient: For a completely mixed batch reactor, the liquid-phase mass transfer coefficient (K_F) can be calculated as follows [10]:

$$K_F = \frac{2.4V_S}{S_C^{0.58}\text{Re}^{0.66}} \quad (15)$$

Where: R: mean radius of adsorbent particles in cm, Re: Reynold's Number, S_C: Schmidt Number, D_L: diffusivity of the adsorbate in the water, and V_S : flux velocity cm/sec

$$S_C = \mu/(\rho_L * D_L) \quad (16)$$

$$\text{Re} = \frac{(2R)^{2/6} * (p/\rho_L * V)^{1/6}}{(\mu/\rho_L)^{0.5}} \quad (17)$$

Re can also calculated by:

$$\text{Re} = \frac{2R\rho_L V_S}{\varepsilon\mu} \quad (18)$$

$$V_S = Q/A \quad (19)$$

$$D_L = \frac{13.26 * 10^{-5}}{\mu^{1.14} * V_b^{0.589}} \quad (20)$$

Where: μ : viscosity of water (g/cm.sec), ρ_L: density of water (g/cm^3), Q : water inflow (m^3/sec), A : fixed bed section (m^2), p : power dissipated in the batch reactor (g.cm^2/sec^3), V : volume of the batch reactor (cm^3), and V_b: molal volume of normal boiling point (cm^3/g.mol).

The solute distribution parameter and the Biot Number: The solute distribution parameter Dg can be found by using the following mathematical expression [23].

$$Dg = \frac{\rho_a qe(1-\varepsilon)}{\varepsilon Co} \quad (21)$$

Where: Dg : solute distribution parameter, dimensionless, qe : The adsorbent phase concentration in equilibrium with influent fluid phase concentration, and ρ_a : Apparent adsorbent density (including the pore volume),(g/cm^3).

The Biot Number Bi can be mathematically expressed as [23]:

$$Bi = \frac{K_F R(1-\varepsilon)}{Ds.Dg.\varepsilon.\Phi} \quad (22)$$

Where: K_F , R, Ds, and Dg as mentioned above, ε = Void fraction (packed bed porosity), dimensionless, and Φ: Sphericity ratio of the surface area of the equivalent-volume sphere to the actual surface of the particle, dimensionless.

Fixed Bed Column Parameters

Stanton number (St): The Stanton number (St) is a ratio of the liquid film mass transfer to the rate of advection through the column. If liquid film transport controls the rate of adsorption, St relates the length of the mass transfer zone the total column length. The Stanton number is defined by the following equation.

$$St_{min} = \frac{K_F T_{min}(1-\varepsilon)}{R.\varepsilon.\Phi} \quad (23)$$

Where:

k_F : liquid film transfer coefficient (cm/sec), T_{min} : the minimum packed bed contact time (min), Φ : Sphericity ratio of the surface area of the equivalent-volume sphere to the actual surface of the particle, dimensionless. ε : packed bed porosity, and R : GAC radius (cm). But St_{min} equals:

$$St_{min} = Ao*Bi + A_1 \quad (24)$$

Where: Ao and A_1 are constants depend on the Freundlich isotherm constant (1/n), and can be found from tables [23].So the packed bed contact time can be calculated by:

$$T_{min} = \frac{R.\varepsilon.\Phi.St_{min}}{K_F(1-\varepsilon)} \quad (25)$$

$EBCT_{min}$: The minimum empty bed contact time ($EBCT_{min}$), that the mass transfer zone MTZ must travel before achieving constant pattern, can be calculated by the following equation [24]:

$$EBCT_{min} = T_{min}/\varepsilon \quad (26)$$

Break through curve

$$T = Ao + A_1(\frac{C}{Co})^{A_2} + \frac{A_3}{1.01 - (\frac{C}{Co})^{A_4}} \quad (27)$$

Where: A_o, A_1, A_2, A_3, and A_4 are constants (mg/l), Co = the influent concentration of the contaminant (mg/l), and C = the effluent concentration of the contaminant (mg/l). The constants, which appear in Eq. 24, are reported in tables [23].

$$t_{min} = T_{min}(Dg+1)\,T \quad (28)$$

$$T_{design} = T_{min} + \frac{t_{design} - t_{min}}{Dg+1} \quad (29)$$

$$EBCT_{design} = T_{design}/\varepsilon \quad (30)$$

Where: t_{design} = The time of the regeneration cycle (sec), Then the required bed volume equals:

$$\text{Bed volume} = Q * EBCT_{design} / \varepsilon \quad (31)$$

A 50% expansion for backwashing must be added to obtain the final design column depth. So the final column depth will be:

$$\text{Column depth} = 1.5 * (BV/\,CA) * SF \quad (32)$$

Where: BV:Bed volume m^3, CA: Column section area m^2, SF: safety factor (1.2 –1.5).

2.2. Design protocol for air stripping tower

Designing an air stripper, by Onda correlation [25], may divide into the following steps:
1-Select the packing material and its properties, 2-Calculating Henry's constant at the design temperature using the equations mentioned above. 3-Calculate the air-water ratio using the following equation, by assuming a value for the stripping factor.

$$\frac{G}{L} = \left(\frac{RP_T}{K_H}\right) \quad (33)$$

Where: L : liquid loading rate (mole/ m^2.sec), G : gas loading rate (mole/m^2.sec), P_T : ambient pressure (1 atm), K_H: Henry's constant (atm), and R : stripping factor.

4-Select a reasonable gas pressure drop, 5- From flood and pressure drop in random-packed towers curve, (Ball. et al 1984), we can calculate the gas mass flux rate for the selected air water ratio, and then calculating the liquid and gas loading rate. In those curves for a specific value to the air pressure and (L`/G`), we can find Y; where:

$$L`/G` = (L/G)*(MW_L/MW_G) \quad (34)$$

$$Y = \frac{G`^2 C_f \mu_L^{0.1.J}}{\rho_G(\rho_L - \rho_G)g_c} \quad (35)$$

Where: MW_G : molecular weight of gas (kg/kmole), MW_L : molecular weight of liquid (kg/kmole), g_c and J are constants = 1, C_f : Packing factor, ρ_L : Density of liquid (kg/m^3), ρ_G : Density of gas (kg/m^3), and Y : is the coordinate in the pressure curve for specific value to the air pressure and (L`/G`). So we can find, from Eq. 35, G` value and then the radius of the packed column by the following equations:

$$L` = G`*L`/G` \quad (36)$$
$$A = Q/L`.\rho_L \quad (37)$$
$$r = (A/\pi)^{0.5} \quad (38)$$

6- Compute mass transfer coefficients:

a) Determine liquid phase diffusion coefficients

$$D_L = \frac{13.26*10^{-5}}{\mu^{1.14} * V_b^{0.589}} \quad (39)$$

Where: μ : viscosity of water (g/cm.sec), ρ_L : density of water (g/cm^3), V_b : LeBas volume of the contaminant (cm^3/g.mol), it can be calculated from.

b) Compute gas phase diffusion coefficient:

$$Dg = \frac{10^{-3} T^{1.75} [\frac{M_A + M_B}{M_A M_B}]^{0.5}}{P_t[(\sum V_A)^{1/3} + (\sum V_B)^{1/3}]^2} \quad (40)$$

Where: D_G : gas diffusion coefficient (m^2/sec), V_A : atomic diffusion volume of air = 20.1 c m^3/mol, V_B : atomic diffusion volume of the contaminant c m^3/mol, M_A : molecular weight of air = 28.966 g/mol, and M_B : molecular weight of the contaminant.

7-Determine the mass transfer coefficient by using Onda correlation:

$$a_w / a_t = 1 - \exp[-1.45(\sigma_c/\sigma_L)^{0.75} \times (\mathrm{Re}_L)^{0.1}(Fr_L)^{-0.05}(We_L)^{0.2}] \quad (41)$$

$$k_L(\rho_L/\mu_L g)^{1/3} = 0.0051(L_m / a_w\mu_L)^{2/3} \times (\mu_L/\rho_L D_L)^{-1/2}(a_t d_p)^{0.4} \quad (42)$$

$$k_G(a_t/D_k) = c(G_M / a_w\mu_G)^{0.7} \times (\mu_G/\rho_G D_G)^{1/3}(a_t d_p)^{-2} \quad (43)$$

$$Re_L = L_M/(a_t\,\mu_L) \quad (44)$$

$$Fr_L = (L^2_M a_t)/(\rho_L{}^2 g) \quad (45)$$

$$We_L = (L^2_M)/(\sigma_L \rho_L\, a_t) \quad (46)$$

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{K_H k_G} \quad (47)$$

$$K_L a = K_L.a_w \quad (48)$$

Where: L' : L_M : liquid mass flux rate (mass/area/time), G' : G_M : gas mass flux rate (mass/area/time), ρ_L : density of liquid (kg/ m^3), ρ_G : density of gas (kg/ m^3), D_A : D_{AB} : molecular diffusion coefficient of a compound in water (m^2/sec), μ_L : liquid viscosity (force/length·time), n and α : Empirical constants , a_t : total specific area of the packing (area/volume), a_w : wetted specific area of the packing (area/volume), σ : surface tension (force/length), L for liquid, and c for the particular packing material, R_{eL} : liquid-phase Reynolds number (dimensionless), Fr_L : liquid-phase Froude number (dimensionless), We_L : liquid-phase Weber number (dimensionless), g : gravitational constant (9.81 m^2/sec), d_p : nominal size of packing (length), D_L : liquid diffusion coefficient (m^2/sec), D_G : gas diffusion coefficient (m^2/sec), K_L : overall liquid-phase mass transfer coefficient, k_L : individual liquid-phase coefficient, k_G = individual gas-phase coefficient, K_La : mass transfer coefficient (sec^{-1}), Q : liquid flow rate (m^3/sec), C_f : packing factor, P : air pressure (atm.),

8-Determine the height of transfer unit using the following equation:

$$HTU = \frac{L}{K_L a C_0} \quad (49)$$

Where: K_La: mass transfer coefficient (sec^{-1}) C_0: molar volume of water (55.6 kmole/m^3)

$$C_0 = \rho_L / MW_L \quad (50)$$

Where: MW_L : molecular weight of liquid (kg/kmole), and ρ_L : density of liquid (kg/ m^3).

9-Determine the number of transfer units using the following equation:

$$NTU = \frac{R}{R-1}\ln\left[\frac{(x_{in}/x_{out})(R-1)+1}{R}\right] \qquad (51)$$

Where: NTU : Number of Transfer Unit , R : stripping factor, x_{in} : influent mole fraction of contaminant in liquid, and x_{out} : effluent mole fraction of contaminant in liquid.

10-Calculate the packing height using the following equation:

$$Z = HTU*NTU \qquad (52)$$

11- Calculating the cost (volume of the packing) and then repeating the above steps for different values of stripping factor to get the minimum cost (volume):

$$Volume = A*Z*SF \qquad (53)$$

Where: SF = Safety Factor (1.2-1.5).

12-Repeat the above steps for different packing materials to get the minimum cost (volume). If water contains different contaminants the final design (volume) must be the largest volume needed for each contaminant. One must remember that the air that flow out the tower is high polluted. So if it is a problem we can direct the outflow air to another treatment process, granular activated carbon for example can be used to remove the contaminant from air, which well be another cost to be added to the total budget.

3. Modeling

The modeling process consists of the following steps:

1- Prepare the data base that includes the contaminant list with all needed properties, packing material list and other constants needed. In this step the all needed curves in the design protocols have been transferred into equations, for example figure 3, flooding and pressure drop correlations for packed towers, has been expressed in six equations depending on air pressure:

P = 50 ATM gives: Y = -0.0026lnx + 0.0043 (54)

P = 100 ATM gives: Y = -0.0056Lnx + 0.008 (55)

P = 200 ATM gives: Y = -0.0098Lnx + 0.015 (56)

P = 400 ATM gives: Y = -0.0175Lnx + 0.0226 (57)

P = 800 ATM gives: Y = - 0.0299Lnx + 0.036 (58)

P = 1200 ATM gives: Y = - 0.0357Lnx + 0.0384 (59)

Where:
P : Air pressure in ATM, x and Y as appeared in Fig. 3.

The same manner was used for all tabulated constants, A_0, A_1, A_2, A_3, and A_4, for example are calculated depending on adsorption intensity (1/n) and Biot number .
On the other hand contaminant properties were included in the program as rules depend on the contaminant chosen from the list, here is an example for benzene rule as it included in the Visual Basic program:

```
 If Combo1.Text = "Benzene" Then
m_p = 278.5
b_p = 353.1
v_p = 95.2
h_c = 0.0058
w_s = 1780  '@20c
l_oc = 2.11
   cout = 0.005
   Formula = "C6H6"
   vb = 110.88
   vp = 111
   mb = 78.11
End If
```

Where:
m_p : melting point, b_p : boiling point, v_p : vapor pressure, h_c : Henry's constant, w_s : water solubility , l_oc : log Kow, cout : Maximum Concentration Level, vb : Atomic Diffusion Volume, vp : LeBas Molar Volume, and mb : Molecular weight.
For the packing material lists each kind has its own croup of rules the following rule, for example connected to ceramic list:

```
If Combo2.Text = "Ber Saddles     38.1mm" Then
cf = 79
sc = 0.061
dt = 38.1
at = 177.2
End If
```

Where: cf : packing factor, sc : surface tension, (kg/sec^2) or (N/m), dt : nominal size (mm), at : surface area (m^2/m^3).

2- Develop the design protocols equations of air stripper and fixed bed carbon adsorber in order to become the internal engine of the software.
3- Merge the steps above to have the final software.
4- Run the program using solved examples to verify that the program execute correctly. This step used to test the software for more than one example in order to validate the software.
Improve the software for our needs such as type of results and dealing with it.
Figs 4 and 5 present the fixed bed adsorber and the air stripper running windows. They present the needed data that is in boxes and the results.

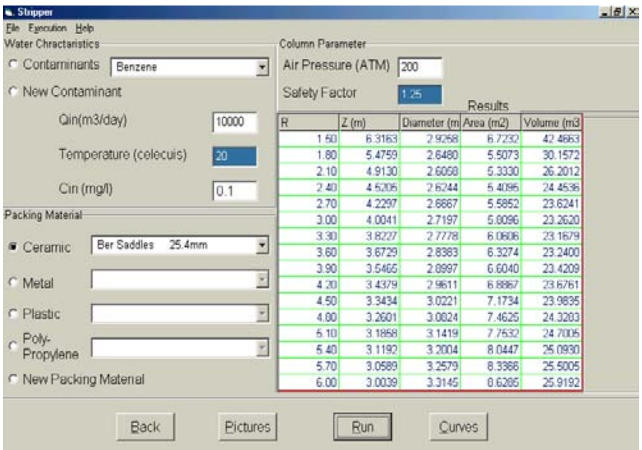

Fig. 4. Air stripper window

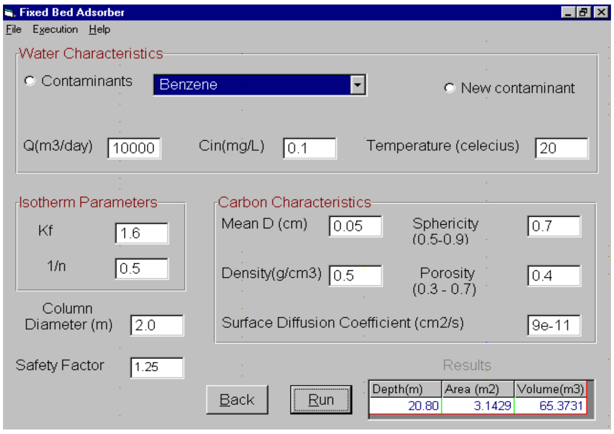

Fig. 5. Fixed bed adsorber window

4. Results

Running the model is a tool to choose between alternatives and to study the effects of changing any parameter on the final volume. Water temperature: Water temperature affects the removal efficiency in the carbon adsorber. At high temperature benzene adsorption on GAC will increase [27]. Moreover, Kim & kang [28] found that the removal efficiency increased from 60% in 10oc to 99% in 25^{o}c. In this regard, running the model shows that, for fixed parameters, rising water temperature decreases the final volume. Figs 6 and 7 present the effect of water temperature on the column size of (FBA) and (AS) respectively. On the other hand, changing column' diameter of the FBA effects its size.

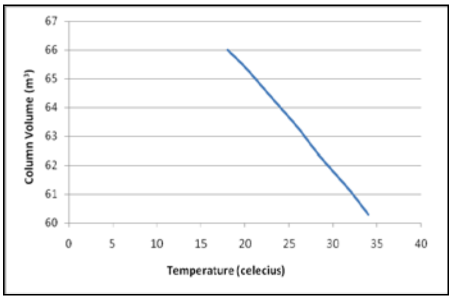

Fig. 6. Water temperature and FBA size

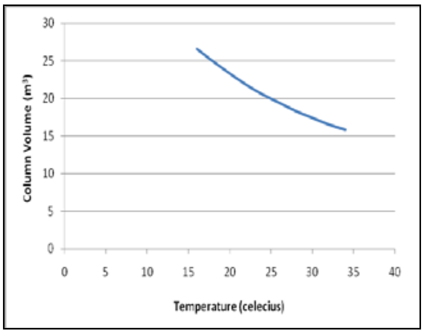

Fig. 7. Water temperature and AS size

Fig. 8 shows that the best column diameter values should lay between 1.2-2.5 m. For air strippers, it was found that increasing air pressure decreases the column volume (Fig. 9). However this decrease may not be economic because that will increase the operation costs. Hence it was noticed that the best values, for air pressure, range between 150 & 200 atm (15.2-20.3 MPa).

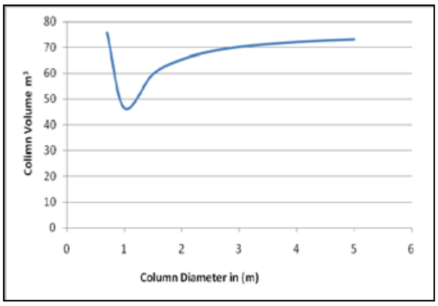

Fig. 8: The relation between FBA volume and its diameter

Moreover, choosing the packing material is very essential in designing air strippers. Alternatives between the same kinds of packing materials may give small effect on the final design. However, changing the packing kind may give an obvious difference. For example, after fixing all other parameters, using different size of plastic flexi ring will range the as volume between 21 and 22 m^3, while changing the packing into metal flexi ring will give 18 m^3 volumes

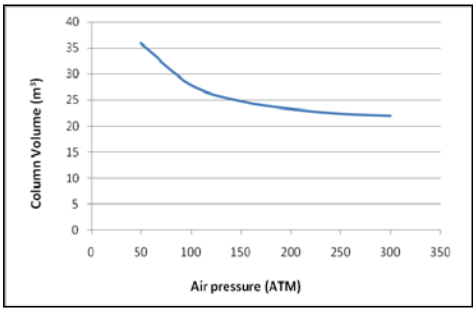

Fig. 9. The relation between AS volume and air pressure

5. Conclusion

The trace organic treatment tool has been developed to be an easy tool that can be used by non-expert user to design air stripping towers and fixed bed adsorbers. The most important sectors in this research are water and economic sectors. From an economic point of view, this model helps in choosing the most economic design depending on the design parameters: size, packing material, aeration, and any expected process, which means managing our decisions depending on our alternatives. This model helps in choosing the most economic design depending on the design parameters: size, packing material, aeration, and any expected process, which means managing our decisions depending on our alternatives. Running the model showed that water temperature affects column size in AS and FBA. Hence, it is advisable, while operation, to sustain at least the design temperature in order not to decrease removal efficiency. the model also shows that the best air pressure values, in as, range between 150-200 atm. moreover, comparisons between the packing price and the tower volume should be carried out before the final decision because there is a strong relationship between the column size and the packing material. Furthermore, changing the FBA diameter, to treat the same contaminated water affects very much the needed volume and the best values range between 1.2-2.5 m.

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