THE ANALYSIS OF A FIXED BED ABSORBER USED FOR THE REMOVAL OF POLLUTANTS FROM WATER

Nada S. A.-Zeki
Chemical Engineering Department – College of Engineering – University of Baghdad - Iraq

ABSTRACT

The aim of this research is conducted to analyze the fixed bed adsorber, which is used for the removal of O-Cresol (0.1 kg/m^{3}), from water using activated carbon as adsorbent. A design procedure was used to predict the theoretical breakthrough curve, mass transfer coefficient, height of the adsorption zone, and the length of the adsorption cycle. A correlation was considered for the breakthrough curve, shown in the following Equation:

$$y=0.015+0.779*x$$

Where, y= C/Co and, x = (Ve-Vb)/(Vx-Vb). The height of the adsorption zone and the length of the cycle were found to be (0.116) m and, (4.29) hr, respectively.

INTRODUCTION

Adsorption is one of the most common advanced wastewater treatment processes, and it's use is increasing in the removal of refractory, toxic substances, and color $^{(1,2)}$.

Inspection of an adsorption isotherm is a relatively simple method of determining the feasibility of using granular activated carbon for a particular application. A liquid phase isotherm shows the distribution of adsorbate between the adsorbed phase and the solution at equilibrium $^{(3)}$.

There are three types of isothermal adsorption classified on Fig (I) .The adsorption of O-Cresol on activated was found to be of the favorable type, that obeying Langmuir Equation which is valid for single -layer, physical adsorption $^{(4)}$.

On considering the case of a binary solution, either gas or liquid, containing a strongly adsorbed solute at concentration (C_o). The fluid is to be passed continuously down through a relatively deep bed adsorbent free of adsorbate.

Downflow is preferred because upflow at high rates might fluidize the particle, causing attrition and loss of fines $^{(5)}$.

The uppermost layer of solid, in contact with the strong solution entering, at first adsorbs solute rapidly and effectively, and what little solute is left in the solution is substantially all removed by the layers in the lower part of the bed.

The effluent from the bottom of the bed is practically solute free as at (C_o) in the lower part of Fig (II)$^{(1)}$. The adsorption zone can be defined as that length of bed in which the concentrations change from breakpoint to exhaustion as occurring at any time. Typical arbitrary choices might be 0.05 C_o for concentration at breakpoint and 0.95 C_o for concentration at exhaustion. As gas is fed to a fresh adsorbent bed, the adsorption zone must be established; it then moves through the bed until it emerges at the discharge end as breakthrough curve. Under certain circumstances, the adsorption zone maintains a constant width as it passes through the bed.

These circumstances are: (1) Isothermal adsorption (the heat of adsorption is small). (2) Feed dilute in adsorbable solute. (3) Adsorption equilibrium curve concave upward to the solution concentration axis.

At constant inflow of feed, an adsorption zone of constant width moves at constant rate through the bed $^{(7)}$.

The shape and the time of appearance of the breakthrough curve influence greatly the method of operating a fixed adsorber. The curves generally have S shape, but they may be steep or relatively flat and in some cases considerably distorted. The actual rate and mechanism of the adsorption process, the nature of the adsorption equilibrium, the fluid velocity, the concentration of solute in feed, and the length of the bed all contribute to the shape of the curve produced for any system. In planning new processes, it is best to determine the break point and the breakthrough curve for a particular system experimentally $^{(8)}$. The design of a fixed bed adsorber and the prediction of the length of adsorption cycle between revirifications require knowledge of the percentage approach to saturation at the break point. This in turn requires the designer to predict the time of the break point and the shape of the breakthrough curve. The unsteady- state circumstances of fixed bed adsorption and the many factors which influence the adsorption, make such computations for the general case very difficult(9). The assumptions, as suggested by Michaels (1952)(9) and are aforementioned, make this procedure using these limitation simpler (8).

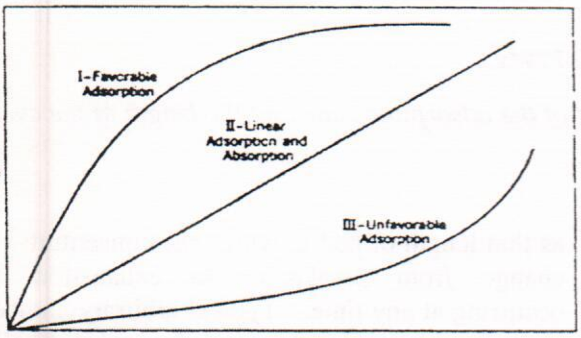

Fig. (I) Types of adsorption

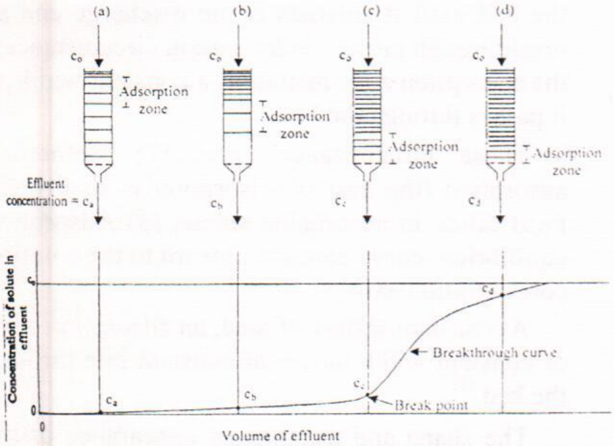

Fig. (II) Adsorption wave(6,9)

Theoretical Analysis

1. The operating line: The line is drawn between the points (0,0) and, ($150x10^{-3}$, $100x10^{-3}$) because initially the carbon column has no solute and so does the effluent, while at the end of the cycle the concentration gets it's original concentration. Experimental equilibrium curve and the operating line, which is shown in Fig. (1), is redrawn from Ref.(4). The breakthrough data is listed in Table (1). Additional data, which is used for the analysis, is listed in Table (2).
2. Certain calculations are made to determine the number of transfer units and to predict the theoretical breakthrough curve. The equilibrium concentration corresponding to each concentration is obtained using the equilibrium data plotted in Fig (1). Results are shown in Table (3).
3. To correlate the breakthrough curve, C/C_o vs. (Ve-Vb)/(Vx-Vb) is plotted and shown in Fig (2).
4. The fractional capacity of the bed at the breakthrough point in the adsorption zone, is given by Equation (1)(1,7,9).

$$f = \int_0^1 \left[1 - \frac{C}{C_o}\right] d\left(\frac{V_e - V_b}{V_x - V_b}\right) \tag{1}$$

This expression shows that f is equal to the area above the breakthrough curve in Fig(2).

5. Overall mass transfer coefficient is calculated using Equation (2) that relates the overall mass transfer coefficient with the superficial mass flow rate F_m and is applicable for water - activated carbon system (1), where $K^o\ \alpha$ is in $Lb/min.ft^3.\ \Delta C$.

$$K^o \alpha = 150(F_m)^{0.5} \tag{2}$$

6. To obtain the height of the adsorption zone, the following equation was adapted:

$$\frac{\delta K\alpha}{F_m} = \int_{C_b}^{C_x} \frac{dC}{C - C^*} \tag{3}$$

7. Saturation was obtained using Equation (4)(1,7):

$$\%Sat. = \frac{D + \delta(f-1)}{D} \times 100 \tag{4}$$

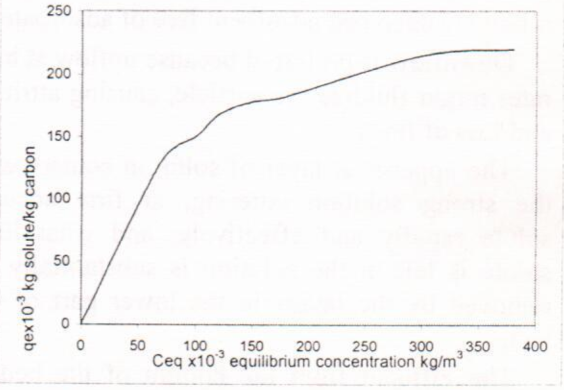

Fig. (1) Adsorption isotherm for O-Cresol on activated carbon

Table (1) Experimental breakthrough data for the adsorption process

$t*10^{-3}$ s	$C*10^3$ kg/m^3	$q*10^3$ kg/kg carbon
0.6	0	5.2
1.2	0	10
1.8	0	15.2
2.4	0	20.8
3	0	26
3.6	0	31.2
4.2	0	36.4
4.8	0	41.6
5.4	0	46.8
6	9	51.5
8.4	17	69.3
9.6	23	78.2
10.8	28.7	85.7
11.4	32.5	98
12	33.6	92.4
12.6	34.8	95.8
13.8	39	102
14.4	42	105
16.8	53	115.4
19.2	65	123.1
20.4	72	126
22.8	80	130.5
24	81	132.5
25.2	81.2	133.5

Table (2) Important data for the adsorption of O-Cresol on activated carbon(4)

$C_o = 100*10^{-3}$ kg/cm^3	$C_b = 9*10^{-3}$ kg/m^3
$C_x = 81.2*10^{-3}$ kg/m^3	M=4.05 kg
d= $1.53*10^{-2}$ m	$P_p = 400$ kg/m^3
S = $1.84*10^{-4}$ m^2	$\varepsilon = 0.7$
D=0.06 m	Q =$3.5*10^{-7}$ m^3 /s
$q\infty = 133*10^{-3}$kg solute/ kg carbon	ρ =1000 kg/m^3

Table (3) Fixed bed calculations

	C X 10^3 kg/m^3	C^*X10^3 kg/m^3	1/(C-C*) x 10*^{3} m^3/kg	$\int_{Cb}^{C} \frac{dC}{C-C*}$	$\frac{V_e-V_b}{V_x-V_b}$	C/C$_o$
C_b	9	6	334	0	0	0.09
	12	10	500	1.217	0.128	0.12
	17	11	167	3.17	0.334	0.17
	53	42	91	6.9	0.724	0.53
	77	68.5	117	8.69	0.913	0.77
	80	71	111	9.49	0.997	0.8
C_x	81.2	75	161.3	9.52	1	0812

RESULTS AND DISCUSSION

1. The height of the adsorption zone, is simply the multiplication of H.T.U by NT.U, which are characteristic values for a given mass transfer problem. This can be illustrated as follows:

$$\frac{\delta K\alpha}{F_m} = \int_{C_b}^{C_x} \frac{dC}{C - C^*} \qquad (3)$$

$$N.T.U. = \int_{C_b}^{C_x} \frac{dC}{C - C*}$$

$$H.T.U = \frac{F_m}{K^o\alpha}$$

2. Overall mass transfer coefficient was obtained from Equation (2) after suitable conversion of units:

   $K^o\alpha = 155.88$ kg/m^3.s.ΔC and,

   $$F_m = \frac{Q\rho}{S} = 1.9\ Kg\ water / m^2 s$$

   substitution in equation (3) gives:

   $$\frac{\delta(155.88)}{1.9} = 9.52$$

   δ=0.116 m. Notice that the height of the adsorption zone (δ) is greater than the height used in the experimental work.

3. Experimental data was used to calculate the mass transfer coefficient. It cannot be theoretically predicted because of the complex

flow pattern of the two phases. The type of packing plays an important role in determination phase flow pattern. In laboratory scale column, mass transfer data differ between the middle and walls of the column. Channeling is also a great problem affecting the flow. In large diameter industrial column, it is extremely important to have the entering liquid uniformly distributed across the packing at the top of the column.

4. Theoretical breakthrough curve was reasonably correlated to fit a straight line with a correlation factor of 96.8% as follows:

   $y=0.015+0.779*x$

   where, $y= C/C_o$ and $x= (Ve-Vb)/(Vx-Vb)$

5. The slope of the breakthrough curve is a function of the adsorption rate. The higher the rate , steeper the curve. A solute that is adsorbed rapidly gives a nearly vertical breakthrough curve. Lower adsorption rates produce longer adsorption zones and, hence a lower fractional saturation (7). The slope of the correlated breakthrough curve is 0.779, i.e. $\theta=37.9°$. This reflects low rate of adsorption.

6. The fractional capacity of the bed at the break point *f* is some function of the slope and area of the breakthrough curve. Numerically Fig (2) gives an area of 0.358, hence, $f=0.642$. Normally it approaches 0.5.

7. % Saturation is calculated by substitution in Equation (4) to give 30.8%. This value is considered small in comparison with the observed values in literatures recorded as (90%) and probably more. It indicates that the bed is unable to receive more solute at this stage or it may do, but with low adsorption rate. Therefore, either additional amount of activated carbon is added or regeneration must be made.

   To obtain a reasonable % saturation of say, 90% , the height of bed is calculated as follows:

   $$0.9=\frac{D+0.116(0.642-1)}{D}$$

   D=0.415 m. Height of adsorption zone, recorded in literatures, is somewhat more than one-fifth the length of the bed.

8. To obtain the breakthrough time the following calculations are made: The column contains $4.05 X 10^{-3}$ kg of carbon, Thus it contains:

   $$\frac{4.05X10^{-3}}{1.84X10^{-4}}=22\,\text{kg/m}^2$$

   At 30.8 % saturation , the carbon contains:

   $22\,(133.5X\,10^{-3})\,(0.308) = 0.\,904$ kg solute/m^2

   The influent introduces :

   $$\frac{3.5X10^{-7}\,X100\,X10^{-3}}{1.84X10^{-4}}=1.9X10^{-4}\,\text{kgsolute/m}^{2}.\text{s}$$

   Therefore, the break point occurs at:

   $$\frac{0.904}{1.9x10^{-4}}=47618s=1.32hr$$

   The breakthrough time was found to be 1.32 hr which means that the bed must be regenerated after this time for the bed is about to be in complete saturation.

5. If the entire column was in equilibrium with the influent, the amount of solute adsorbed per unit area of adsorber, would be:

   $22x133.5x10^{-3}= 2.937$ kg solute /m^2

   Therefore, the time for completion will be:

   $$t_x=\frac{2.937}{1.9X10^{-4}}=15457.89s=4.29hr$$

   $$V_x=(15457.89)(1.9)=29370\ \text{kgwater/m}^2$$

10. The amount of solute adsorbed per m^2 of cross sectional area of the bed is calculated as follows:

    $$V_b=(4761)(1.9)=9046\ \text{kgwater/m}^2$$

    2.937-0.9046= 2.0324 kg solute /m^2, this amount represents the total capacity of carbon between (x to b). It is also given as $(V_x-V_b)C_o/\rho$

11. By solute material balance :

    $F_m C_o= \rho$ ms $q\infty$

    Where m_s represents the superficial mass rate of saturation of the adsorbent (i.e. mass of adsorbent saturated per unit time per unit area)(1). So: $m_s = 1.428\ x10^{-3}$ kg/m^2.s

12. The volume of water being treated at the break point is:

    9046/1000=9.046 m^3/m^2

    and the total mount of water treated is :

    29370/1000=29.37 m^3/m^2

CONCLUSIONS

The following conclusions were found from the present research:

A. The height of the adsorption zone of 0.116 m is greater than the height of carbon bed which is used in the experimental work.(0.06m.). This causes a decrease in the fractional saturation at the break point. It was found that the height of the carbon bed, to do this adsorption process properly, to be 0.415 m.

B. Experimental breakthrough data is fitted to a straight line equation, and is given as:

$$y = 0.015 + 0.779 * x$$

where, $y = C/Co$ and $x = (Ve-Vb) / (Vx-Vb)$

C. The amount of water treated from the beginning of the cycle to the break point is 9.046 m^3/m^2.

D. Fractional saturation of the bed at the break point is 30.8%. It is considered low among other adsorption processes.

E. The time of break point is 1.32 hr while the total cycle time is 4.29 hr.

F. The rate of saturation of carbon is 1.428×10^{-3} $kg/m^2.s$.

NOMENCLATURE

C	Solute concentration in solution (kg/m^3)
C^*	Equilibrium concentration of the solute in solution (kg/m^3)
C_o	Initial concentration (kg/m^3)
C_b	Effluent concentration at break point (kg/m^3)
C_x	Effluent concentration at time of exhaustion (kg/m^3)
d	Diameter of the column (m)
D	Depth of the carbon bed(m).
F_m	Superficial mass rate of flow to the adsorber (kg/m^2s)
f	Fractional capacity of bed.
K^0	Overall Mass transfer coefficient (kg/m^2s). ∞
m	Mass of adsorbent in the column(kg).
Q	Volumetric flow rate (m^3/s).
q_e	Amount of solute adsorbed per unit mass of solid adsorbent at equilibrium(kg/kg).
q_∞	Amount of solute adsorbed per unit mass of solid adsorbent at complete saturation.(kg/kg).
S	Cross sectional area (m^2)
t_b	Time at break point (s)
t_x	Total time (s)
V_b	Quantity of effluent from the adsorber at break point (kg/m^2)
V_e	Quantity of solute free water (kg/m^2)
V_x	Quantity of effluent from the adsorber at exhaustion (kg/m^2)
Z	Bed height (m)

Greek letters

α	External surface area of solid per unit volume m^{-1}
δ	Height of adsorption (m)
Δ	Difference (--)
ρ	Density of water
ρ_p	Packed density of activated carbon
θ	Angle

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