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Determination of Volumetric Mass Transfer Coefficient in Fixed Bed Adsorption

Adil A. Al-Hemiri and Farah Y. Al-Kaisy

Chemical Engineering Department - College of Engineering - University of Baghdad - Iraq

Abstract

This work was conducted to determine the volumetric mass transfer coefficient (Ky.a) in fixed bed adsorption using hexane-benzene mixture by adsorption onto a fixed bed of white silica gel.Benzene concentration was measured by gas chromatography. The effect of feed flow rate and initial concentration of benzene in hexane-benzene mixture on the volumetric mass transfer coefficient and on the adsorption capacity of silica gel was investigated.

In general, the volumetric mass transfer coefficient increases with increasing hexane flow rate, and with increasing initial concentration of benzene in the mixture. The ultimate value of (Ky.a) was at 53 ml/min of hexane flow rate with benzene initial concentration of (6.53 wt. %), and it was (99.4 kg/m3.s).

The adsorptive capacity of silica gel increases with decreasing hexane flow rate, as with increasing initial concentration of benzene in the mixture. The best adsorptive capacity of the imported silica gel (100 g of imported silica gel yielded 120 ml of benzene-free effluent) was achieved with the grade (1.18-5 mm) in size at a hexane flow rate 15 ml/min.

Keywords: mass transfer coefficient, adsorption, fixed bed.

Introduction

Most adsorbent are highly porous materials, and adsorption takes place primarily on the walls of the pores or at specific sites inside the particle. Separation occurs because differences in molecular weight, shape, or polarity cause some molecules to be held more strongly on the surface than others or because the pores are too small to admit the larger molecules [1]. The commercial materials (solid adsorbents) include a variety of clays, chars, activated carbons, gels, alumina, silicate and resinous materials [2]. Solid adsorbents are usually porous granular particles used in fixed beds [3].

Separation in a fixed bed of adsorbent is, in virtually all practical cases, an unsteady state rate controlled process. This means that conditions at any particular point within the fixed bed vary with time. Adsorption therefore occurs only in a particular region of the bed, known as the mass transfer zone, which moves through the bed with time [4].

The first factor which must be realized in considering a fixed-bed operation is the equilibrium or capacity requirement. A bed of a certain size has a fixed capacity for the adsorbate entering in the feed stream. In addition, the capacity of the adsorbent for smaller concentrations of the adsorbate in the entering stream defines the shape of the equilibrium curve and is important in fixed bed operation [5].

Five mechanisms are associated with the spreading of a concentration wave in a fixed bed .These are: (a) axial dispersion, (b) external mass transfer, (c) pore diffusion, (d) surface diffusion (or particle diffusion), (e) reaction kinetics [6].

The MTZ or adsorption zone is defined as the portion of the bed in which adsorption is occurring [4].

The MTZ length is independent of the bed length .It is function of type of adsorbent , adsorbent particle size, fluid properties, adsorbate concentration in entering fluid, adsorbate concentration in the adsorbent (if the latter has

been fully reactivated), temperature of the adsorbent bed and pressure [7-8].

In this investigation, white silica gel was selected to adsorb benzene from hexane-benzene mixture. A simplified treatment due to [9] is readily used but is limited to isothermal adsorption from dilute feed mixtures and to cases where the equilibrium adsorption isotherm is concave to the solution-concentration axis, where the adsorption zone is constant in height as it travels through the adsorption column, and where the height of the adsorbent bed is large relative to the height of the adsorption zone.

From the above mentioned treatments, the volumetric mass transfer coefficient (Ky.a) is obtained from the well known model:

$$K_Y \cdot a = \frac{M}{Z_a} \cdot \int_{Y_B}^{Y_E} \frac{dY}{Y - Y^*} \qquad (1)$$

Experimental Work

An experimental apparatus shown in figure 1 is constructed for the experimental work.

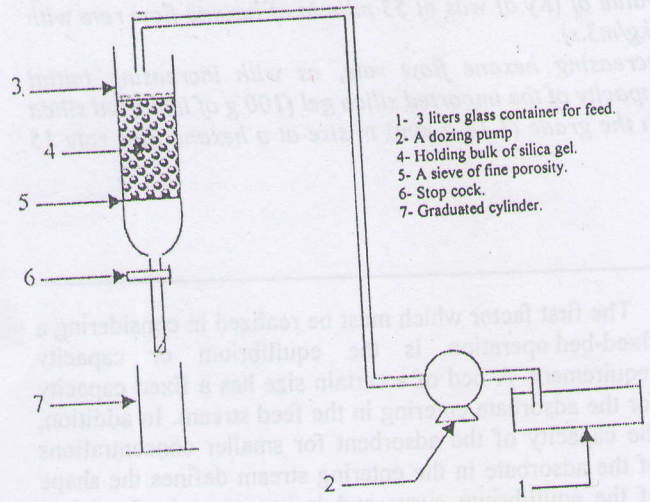

Fig. 1 The experimental equipment

A known quantity of silica gel is placed in the adsorption column and packed by gentle tapping through its length. The feed (hexane and benzene solution) in whatever amount required, is introduced at the top of the column by means of the dozing pump at the desired flow rate. When the volume of effluent for a desired fraction has collected in the receiver. The product is collected at different time intervals for obtaining the concentration of adsorbate at each time to build up the breakthrough curve. The concentration of each fraction is measured by the gas chromatography. Breakthrough curves are determined by plotting effluent concentration against volume.

Twenty runs were conducted using 100g of imported silica gel (1.2-5 mm) in size at a hexane flow rate of (15, 28, 40, and 53 ml/min) and different concentrations of benzene in hexane (6.53%, 5.24%, 3.94%, 2.638%, and 1.323% by weight).

A chromatographic system was used to analyze the inlet and outlet from the adsorption column, the chromatographic system used consists of three essential elements. These are: injection system, temperature – controlled column, and detector.

Results and Discussion

Adsorption isotherm

Figure 2 shows the adsorption isotherm for (hexane-benzene) solution on imported silica gel of size (1.18-5 mm) at a temperature of 28°C. The isotherm is somewhat concave upward, because relatively low silica gel loadings were obtained and it leads to quite long mass transfer zones in the bed. That is the isotherm is of unfavorable type.

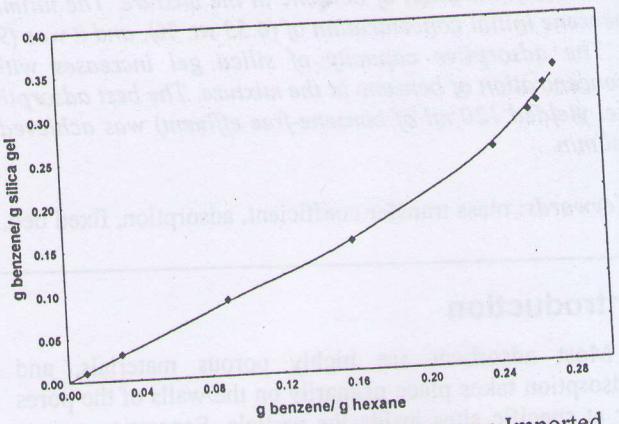

Fig. 2 Adsorption Isotherm for Benzene on Imported Silica Gel at a temperature (T = 28 °C)

Effect of hexane flow rate on adsorption capacity of silica gel

The effect of hexane flow rate on the adsorption capacity of imported silica gel of size (1.18-5 mm) for benzene is shown respectively in figures 3 to 7.

Generally, the benzene concentration in effluent increases with increasing hexane flow rate. That is the adsorptive capacity of silica gel for benzene is inversely proportional to the hexane flow rate. This can be caused by the increasing residence time at lower hexane flow rates.

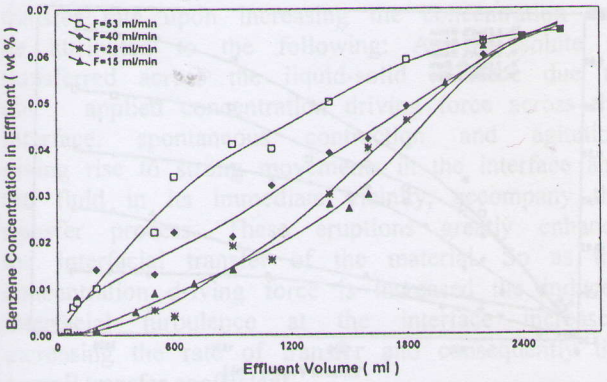

Fig. 3 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel at initial Concentration of Benzene Co= 6.53 wt. % at Various Hexane Flow Rates.

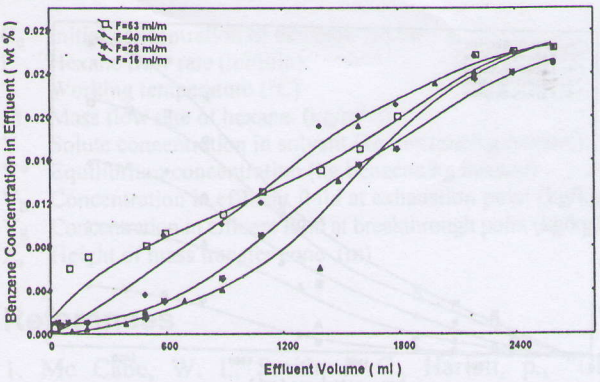

Fig. 6 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel at Initial Concentration of Benzene Co=2.638 wt. % at Various Hexane Flow Rates.

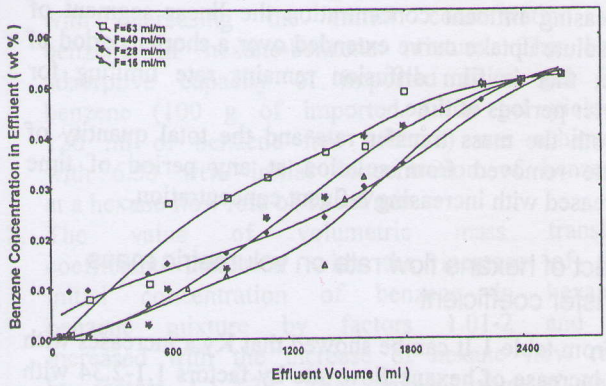

Fig. 4 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel at Initial Concentration Co=5.24 wt. % at Various Hexane Flow Rates.

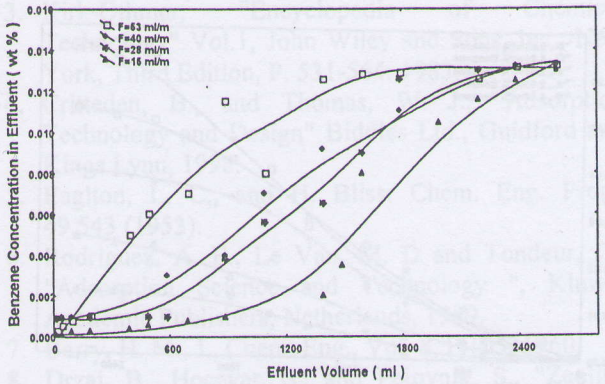

Fig. 7 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel at Initial Concentration of Benzene Co=1.323 wt. % at Various Hexane Flow Rates.

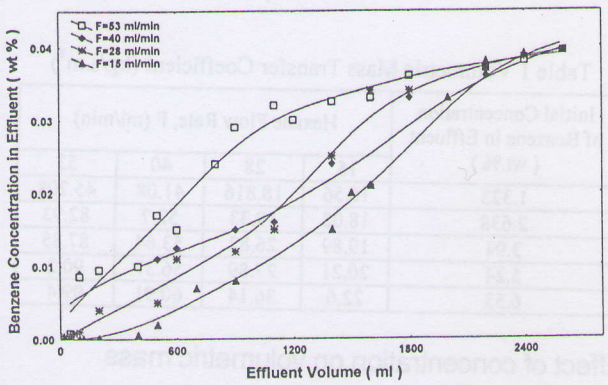

Fig. 5 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel at Initial Concentration of Benzene Co=3.94 wt. % at Various Hexane Flow Rates.

Effect of initial concentration of benzene on adsorption capacity of silica gel

The effect of initial concentration of benzene in hexane-benzene mixture on the adsorption capacity of imported silica gel of size (1.18-5mm) is shown respectively in figures 8 to 11.

The total quantity of solute removed from solution at any period of time increased with increasing influent concentration.

The effect of the initial benzene concentration in the flow is one of the limitation factors and a main process parameter. Increasing the inlet benzene concentration increases the slope of the break through curve, reducing the volume treated before adsorbent regeneration. Increasing inlet benzene concentration at constant flow rate decreases the through put until break through. This may be caused by saturation of the adsorbent more quickly with high benzene concentrations, thereby decreasing the break through time. It was noted that with

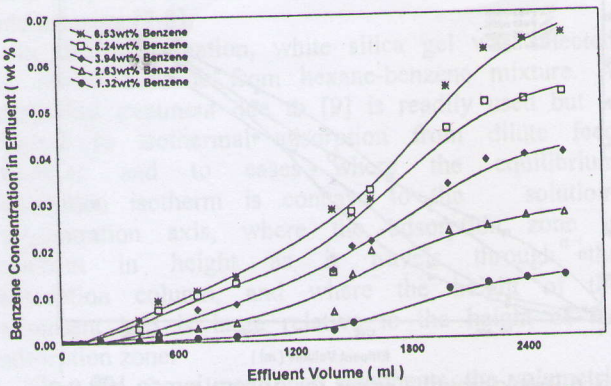

Fig. 8 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel of Various Concentration of Benzene at a Hexane Flow Rate (F=15 ml / min).

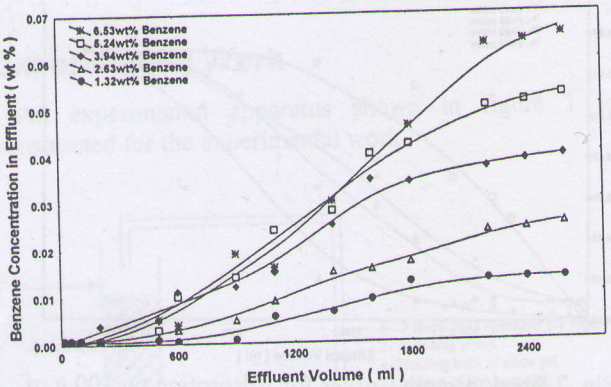

Fig. 9 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel of Various Concentration of Benzene at a Hexane Flow Rate (F=28 ml / min).

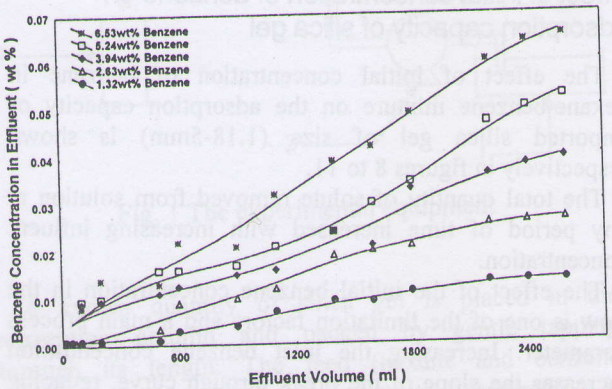

Fig. 10 Breakthrough Curves for Adsorption on 100 g of Imported Silica Gel of Various Concentration of Benzene at a Hexane Flow Rate (F=40 ml / min).

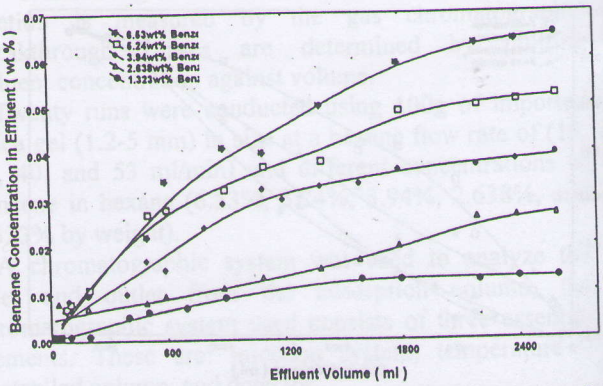

Fig. 11 Breakthrough Curves for Adsorption on100 g of Imported Silica Gel of Various Concentration of Benzene at a Hexane Flow Rate (F=53 ml / min).

increasing influent concentration the linear segment of the solute uptake curve extended over a shorter period of time; that is film diffusion remains rate limiting for shorter periods of time.

Both the mass transfer rate and the total quantity of solute removed from solution at any period of time increased with increasing influent concentration.

Effect of hexane flow rate on volumetric mass transfer coefficient

From table 1 It can be showed that Ky.a increases with the increase of hexane flow rate by factors 1.1-2.34 with initial concentration of benzene in hexane-benzene mixture of 6.53, 5.24, 3.94, 2.683 and 1.323 wt% at hexane flow rates of 15, 28, 40, and 53 ml/min. The ultimate flow rate was 53 ml/min because the value of Ky.a was the maximum (Ky.a = 99.4 kg/m3.s).

Table 1 Volumetric Mass Transfer Coefficient ($kg/s.m^3$)

Initial Concentration of Benzene in Effluent (wt.%)	Hexane Flow Rate, F (ml/min)			
	15	28	40	53
1.323	16.56	18.816	41.08	45.708
2.638	18.08	19.33	52.7	82.93
3.94	19.89	26.82	53.64	87.85
5.24	20.21	27.89	56.37	90.2
6.53	22.6	36.14	60.91	99.4

Effect of concentration on volumetric mass transfer coefficient

From table 1, it was observed that Ky.a increases of initial concentration of benzene in hexane-benzene mixture by factors 1.01-2 at hexane flow rate of 15, 28, 40 and 53 ml/min with initial concentration of benzene of 6.53, 5.24, 3.94, 2.683 and 1.323 wt%.

The increase of mass transfer coefficient and the transfer rate upon increasing the concentration can be attributed to the following: As the solute is transferred across the liquid-solid interface due to the applied concentration driving force across the interface, spontaneous contraction and agitation giving rise to strong movements in the interface and the fluid in its immediate vicinity, accompany the transfer process. These eruptions greatly enhance the interfacial transfer of the material. So as the concentration driving force is increased the induced interfacial turbulence at the interface increases, increasing the rate of transfer and consequently the overall transfer coefficient.

Conclusions

1. The adsorptive capacity of imported silica gel increases with decreasing hexane flow rate and with increasing the initial concentration of benzene in hexane-benzene mixture. The best adsorptive capacity of imported silica gel for benzene (100 g of imported silica gel yielded 120 ml of benzene free effluent) was achieved with 6.53 wt% initial concentration of benzene at a hexane flow rate of 15 ml/min.
2. The value of volumetric mass transfer coefficient increased with the increase of the initial concentration of benzene in hexane-benzene mixture by factors 1.01-2 and it increased with the increase of hexane flow rate by factors 1.1-2.34. The highest value of Ky.a (99.4 kg/m3.s) was at hexane flow rate of 53 ml/min and 6.53 wt% initial concentration of benzene in hexane-benzene mixture.

Nomenclature

C_0 Initial concentration of benzene (wt.%)
F Hexane flow rate (ml/min)
T Working temperature (°C)
M Mass flow rate of hexane. ($kg/m^2.s$)
Y Solute concentration in solvent (kg benzene/kg hexane)
Y* Equilibrium concentration (kg benzene/kg hexane)
Y_B Concentration in effluent fluid at exhaustion point (kg/kg)
Y_E Concentration in effluent fluid at breakthrough point (kg/kg)
Z_a Height of mass transfer zone (m)

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