

Chapter 19

ADSORPTION ON ACTIVATED CARBON

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ABSTRACT

Adsorption on activated carbon is an effective method for removing volatile organic compounds (VOC) from gases. In this article, results are presented for adsorption capacity as a function of the VOC concentration in the gas. The correlation constants are displayed in an easy-to-use tabular format that is especially applicable for rapid engineering usage with the personal computer or hand calculator.

The results for adsorption capacity are applicable for conditions (concentrations in parts per million range in gas at 25 C and 1 atm) which are encountered in air pollution control. Correlation and experimental results are in favorable agreement.

INTRODUCTION

Physical and thermodynamic property data for organic compounds are especially helpful to engineers and scientists in industry. In particular, capacity data for adsorption of volatile organic compounds (VOC) on activated carbon is becoming increasingly important in engineering and environmental studies because of more and more stringent regulations regarding air emissions.

In this article, results are presented for adsorption capacity as a function of the VOC concentration in the gas. The results are usable in engineering and environmental studies. As an example of such usage, capacity data issuing from the correlation are useful in the engineering design of carbon adsorption systems to remove trace pollutants from gases.

ADSORPTION CAPACITY CORRELATION

The correlation for adsorption on activated carbon is based on a logarithmic series expansion of concentration in the gas:

$$\log_{10} Q = A + B [\log_{10} y] + C [\log_{10} y]^2 \quad (19-1)$$

where Q = adsorption capacity at equilibrium, g of compound/100 g of carbon
 y = concentration in gas at 25 C and 1 atm, parts per million by volume, ppmv
 A , B , and C = correlation constants

The correlation constants (A , B , and C) are given in Table 19-1. The correlation constants in the table were determined from regression of the available data for adsorption on activated carbon. The tabulation is arranged by carbon number (C1, C2, C3, ..., C14). This provides ease of use in quickly locating data using the chemical formula. The tabulation also gives the adsorption capacity at concentrations of 10, 100, and 1000 parts per million by volume (ppmv) in gas.

A comparison of correlation and experimental data is shown in Figure 19-1 for a representative compound. In the figure, adsorption capacity is for conditions (concentrations in parts per million range in gas at 25 C and 1 atm) which are encountered in air pollution control. The graph discloses favorable agreement of correlation and experimental data.

ESTIMATION EQUATION

In preparing the correlation, a literature search was conducted to identify source publications (1-39) relative to experimental data and property values for estimates. The publications were screened and copies of appropriate data were made. These data were then keyed into the computer to provide a database of adsorption capacity values at different concentrations (partial pressures) for which experimental data are available. The database also served as a basis to check the accuracy of the correlation.

Upon completion of data collection, estimation of adsorption capacity for the remaining compounds was performed. The following equation (developed by Calgon, 7) was used for estimation of the equilibrium

adsorption capacity of activated carbon as a fifth order polynomial function of its adsorption potential:

$$\log_{10} Q = A + B \mu + C \mu^2 + D \mu^3 + E \mu^4 + F \mu^5 \quad (19-2)$$

where Q = adsorption capacity at equilibrium, cm³ of liquid compound/100 g of carbon
 μ = adsorption potential of compound, $T/(V_i \Gamma_i) \log(P_i^{\text{sat}}/p_i)$
 T = temperature, K

V_i = liquid molar volume of compound, $\text{cm}^3/\text{g-mol}$
 Γ_i = relative polarizability, $[(n^2-1)/(n^2+1)]_i / [(n^2-1)/(n^2+1)]_{n\text{-heptane}}$
 n = refractive index
 P_i^{sat} = vapor pressure of compound, atm
 p_i = partial pressure of compound, atm
 $A = 1.71$
 $B = -1.46\text{E-}02$
 $C = -1.65\text{E-}03$
 $D = -4.11\text{E-}04$
 $E = 3.14\text{E-}05$
 $F = -6.75\text{E-}07$

For the above equation, data for refractive index are from compilations by Yaws (present work), Texas A & M (26,27) and DIPPR (28). Data for vapor pressure and liquid molar volume are from compilations by Yaws (32-36).

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EXAMPLES

The correlation maybe used for determining adsorption capacity of activated carbon for removing compounds from gases. Examples are given below.

Example 1 The air from a paint spraying operation contains 10 ppmv of n-butanol ($\text{C}_4\text{H}_{10}\text{O}$). Estimate the adsorption capacity of activated carbon for removing the compound at 25 C and 1 atm.

Substitution of the coefficients from the tabulation and concentration into the correlation equation yields:

$$\log_{10} Q = 0.8988 + 0.32534 [\log_{10} (10)] - 0.03648 [\log_{10}(10)]^2 = 1.18767$$

$$Q = 10^{1.18767}$$

$$Q = 15.41 \text{ g of n-butanol/100 g of carbon}$$

Example 1 The air from an industrial operation contains 10 ppmv of cyclohexane (C_6H_{12}). Estimate the adsorption capacity of activated carbon for removing the compound at 25 C and 1 atm.

Substitution of the coefficients from the tabulation and concentration into the correlation equation yields:

$$\log_{10} Q = 0.720 + 0.25698 [\log_{10} (10)] - 0.01550 [\log_{10}(10)]^2 = 0.96142$$

$$Q = 10^{0.96142}$$

$$Q = 9.15 \text{ g of cyclohexane/100 g of carbon}$$

OPERATION AND DESIGN

In actual operation under plant conditions, the capacity of an adsorption bed will seldom achieve equilibrium. Copper and Alley (6) indicate bed capacity at 30 to 40% of equilibrium for plant operating conditions. Damie and Rogers (7) in the EPA design manual suggest a working factor of 3 for design of adsorption beds. The total carbon requirements for an adsorption system is obtained by determining carbon required from equilibrium capacity and then multiplying by the working factor.

Factors affecting adsorption bed capacity are discussed by Copper and Alley (6), Damie and Rogers (7) and Gram and Ramaratnam (25). These include loss due to adsorption zone; loss due to heat wave (adsorption is an exothermic process); loss due to moisture in entering gas and loss due to residual moisture on the carbon.

Representative adsorption systems for removing organic compounds from gases are shown in

Figures 19-2, 19-3 and 19-4. Figure 19-2 shows an adsorption system with recovery of the organic (such as a solvent) using steam for regeneration. Figure 19-3 applies to an adsorption system with thermal or catalytic oxidation of the organic removed from the gas by carbon adsorption. In Figure 19-4, the organic is initially removed from wastewater by air stripping. The air leaving the stripper contains the organic and is then sent to the adsorption system for recovery of the organic. This last system can be used to recover organics (such as benzenes) from process wastewater encountered in the chemical and petroleum refining industries.

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