

Binary Vapor Adsorption by Activated Carbon Under Dynamic Flow Conditions

Leonard A. Jonas and Eric B. Sansone

Environmental Control and Research Program
NCI-Frederick Cancer Research Facility
Program Resources, Inc.
P. O. Box B
Frederick, MD 21701

Introduction

For the system of a mixture of gases and an activated carbon the number of experimental variations possible is n^3 where n is the number of gases. Thus, for a binary mixture of gases A and B, 2^3 or 8 variations of adsorption studies can be made:

1. Gases A and B introduced concurrently into a clean bed of activated carbon.
2. Gas A introduced into carbon with previous exposure to Gas B.
3. Gas B introduced into carbon with previous exposure to Gas A.
4. Gases A and B introduced concurrently into carbon with previous exposure to Gas B.
5. Gases A and B introduced concurrently into carbon with previous exposure to Gas A.
6. Gas A introduced into carbon with previous exposure to Gases A and B.
7. Gas B introduced into carbon with previous exposure to Gases A and B.
8. Gases A and B introduced concurrently into carbon with previous exposure to Gases A and B. This variation can be considered the Identity Relation only if the mole fractions of A and B are identical for both the present and previous exposures.

Experimental

The adsorbates benzene, chloroform, and carbon tetrachloride used in this study were all of high purity. The gas adsorption test apparatus used has been previously described in detail (1).

The procedure for generating the vapors, establishing the gas flow rates, and preparing and packing the carbon beds have been previously described (2). Various adsorbent bed weights (1-2.5 g) were exposed to the vapor(s) drawn into the bed at 285 cm³/min. corresponding to a superficial linear velocity of 323 cm/min. at 23°C. The inlet vapor concentrations represented a relative pressure of 0.094 at 23°C for benzene, chloroform, and carbon tetrachloride when tested separately as well as when binary mixtures of these gases were tested concurrently. The relative pressures are calculated from the ideal gas law. In all cases,

the breakthrough time t_b (min) was the time when the exit or breakthrough concentration of the gas was 1% of its inlet concentration ($C_x/C_o = 0.01$).

Results

For the binary gas mixtures, run either concurrently or sequentially into the carbon, Table 1 lists the separate contribution of each gas to the

Table 1. Adsorption characteristics of NACAR G-352 lot 2905 activated carbon

Gas*	Mole fraction	t_b vs W eqn.	Ads. cap. W_e (g/g)	Ads. space W_v (cm ³ /g)
Benzene	1.0	$t_b = -47.89 + 43.22W$	0.432	0.493
CCl ₄	1.0	$t_b = -46.32 + 36.19W$	0.832	0.524
Chloroform	1.0	$t_b = -24.88 + 21.04W$	0.645	0.435
Benzene and CCl ₄ concurrently	0.461 0.539	$t_b = -39.74 + 20.88W$ $t_b = -35.57 + 18.12W$	0.208 0.417	0.237 0.263
Benzene and Chloroform concurrently	0.333 0.667	$t_b = -13.38 + 14.81W$ $t_b = -17.54 + 14.39W$	0.147 0.440	0.168 0.297
Benzene then CCl ₄ sequentially	1.0 1.0	** $t_b = -47.02 + 31.20W$		0.054 0.458
CCl ₄ then Benzene sequentially	1.0 1.0	** $t_b = -52.41 + 39.45W$		0.060 0.440

* liquid density (g/cm³): benzene 0.8761; CCl₄ 1.5881; chloroform 1.4832

** calculated by $C_o Q t / (W - W_e) d_1$

adsorption space utilization of the carbon. Table 2 summarizes the adsorption space utilization of the carbon under conditions of single gas inputs, concurrent binary gas inputs, and sequential binary gas inputs. The mean adsorption space utilized for the NACAR G-352 carbon, under seven dif-

Table 2. Adsorption space (W_v) of NACAR G-352 lot 2905 activated carbon

Adsorption* space W_v (cm^3/g)	Source
0.493	t_b vs W eqn. for benzene
0.524	t_b vs W eqn. for CCl_4
0.435	t_b vs W eqn. for chloroform
0.500	t_b vs W eqn. for concurrent benzene and CCl_4
0.465	t_b vs W eqn. for concurrent benzene and chloroform
0.512	Mean input of benzene at 0.11 t_b plus t_b vs W eqn. for subsequent CCl_4
0.500	Mean input of CCl_4 at 0.11 t_b plus t_b vs W eqn. for subsequent benzene

0.490 mean
 ± 0.030 standard deviation
 $\pm 6.12\%$ coefficient of variation

* $P/P_0 = 0.094$ at 23°C

ferent input conditions for three different gases, was a constant $0.490 \text{ cm}^3/\text{g}$ with a standard deviation of ± 0.030 when the gases were at a relative pressure of 0.094 at 23°C . Since the adsorption space calculated for this carbon, using the Dubinin-Radushkevich equation for equilibrium conditions, was $0.524 \text{ cm}^3/\text{g}$, the mean experimental value of $0.490 \text{ cm}^3/\text{g}$ showed only a 6.49% deviation.

Analysis

An analysis of the test results shows that regardless of the type of gas or gases introduced to the carbon, or their order of introduction, the carbon cannot adsorb gases beyond its adsorption space capacity at a fixed relative pressure and temperature. The adsorption space W_v of $0.524 \text{ cm}^3/\text{g}$ for this NACAR G-352 carbon, under conditions of a relative pressure of 0.094, a temperature of 23°C , and a breakthrough penetration of 1% ($C_x/C_0 = 0.01$), was calculated with the D-R equation using the previously published (1) values of $0.700 \text{ cm}^3/\text{g}$ for W_0 and $14.9 \times 10^{-8} (\text{cal/mole})^{-2}$ for k . It can be seen from Table 2 that the mean adsorption space for this carbon from tests at experimental conditions as diverse as single gas ad-

sorption, concurrent binary gas adsorption (variation 1), and sequential gas adsorption (variations 2 and 3) was $0.490 \text{ cm}^3/\text{g}$, deviating from the calculated value by only 6.49%.

The limitation of the adsorption space in a carbon, under specified test conditions of relative pressure, temperature, and breakthrough concentration, provides the means whereby one can predict the adsorption characteristics of all 8 variations of the binary gas mixtures, and probably those of the higher multiple gas mixtures.

Discussion

The prediction of the adsorption capacity of binary gases introduced concurrently to the carbon was based on the finding that for each gas it would be equal to its capacity, at the same relative pressure, if it were by itself multiplied by its mole fraction in the mixture. This predictive method, described in detail in our previous paper (3), would apply not only to binary but also to any multiple gas mixture introduced concurrently to the carbon. In this study we have extended the predictive method for mixed gas adsorption capacity to the various cases wherein the gases may be introduced sequentially to the carbon. The invariance of the adsorption space in the carbon, at fixed relative pressure and temperature, is the key to the predictive method since it indicates that each gas occupies adsorption sites and fills up adsorption space volume which is unoccupied by the gases at any point in time. Thus, for the organic gases used in this study, each gas introduced sequentially does not displace the previous gas but rather seeks out and bonds with unoccupied active sites within the carbon.

Acknowledgement

Research sponsored by the National Cancer Institute under Contract N01-CO-23910 with Program Resources, Inc.

References

1. Jonas, L.A. and J.A. Rehrmann: Predictive Equations in Gas Adsorption Kinetics. Carbon 11:5964 (1973).
2. Sansone, E.B., Y.B. Tewari and L.A. Jonas: Prediction of Removal of Vapors from Air by Adsorption on Activated Carbon. Environ. Sci. Technol. 13:1511-1513 (1979).
3. Jonas, L.A., E.B. Sansone, and T.S. Farris: Prediction of Activated Carbon Performance for Binary Vapor Mixtures. Am. Ind. Hyg. Assoc. J. 44:716-719 (1983).