Techniques for Determining Mixed Vapor Adsorption
On Activated Carbon

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Adsorption capacity of an adsorbent is an important parameter in the design of air purification systems. Such adsorbents are employed in gas masks and chemically protective clothing. In practice, the species to be adsorbed may be accompanied by other species in a multicomponent mixture which may or may not compete with the adsorption of the vapor species of interest. Therefore, the study of multicomponent adsorption on an adsorbent is quite important. There are two main methods currently being employed to study multicomponent adsorption: 1) equilibrium and 2) dynamic. Although there has been considerable study involving equilibrium properties of adsorbate/adsorbent systems, relatively few studies have considered adsorption kinetics. Of those reported[1-3] most have dealt with the kinetics of single vapor adsorption behavior.

In the present work, two experimental methods for determining multicomponent adsorption capacity of an adsorbent have been investigaged. The adsorbent was BPL activated carbon.[4,5]

1) Equilibrium Method

In principle, there are two basic methods for the determination of equilibrium adsorption isotherms of a mixture namely, the gravimetric method and the volumetric method. Of these two, the gravimetric method has been primarily employed because of its greater accuracy at small adsorption capacities and, also, because of experimental restraints associated with the volumetric method.

The apparatus used for the determination of equilibrium adsorption isotherms is shown in Figure 1. A detailed description of the method is given elsewhere.[4-6] The apparatus consists of a microbalance, vacuum pumps and solvent reservoirs. An adsorbent sample (activated carbon) is suspended on the balance beam in a small glass weighing boat which has been tared with calibration weights. Adsorbate vapor of known composition is introduced in the adsorption chamber. A change in mass of the adsorbent due to adsorption is displayed as an electrical signal from the balance and is recorded on a strip chart recorder. The equilibrium pressure is recorded by a pressure gauge. Each adsorbent is degassed for 5-6 hours under vacuum of 10^{-5} torr before being exposed to an adsorbate vapor. When the adsorbent sample reaches a constant weight, it is brought to room temperature and the adsorbate is introduced in the system.

Typical adsorption isotherms for the $CHCl_3$/CCl_4 binary vapor mixture are shown in Figure 2. A disadvantage of this method is that the equilibrium adsorbate composition cannot directly be determined. However, once the total adsorption is known, Lewis's equation[7] can be employed to obtain the equilibrium adsorbate composition i.e. the proportion of each component in the adsorbed phase.

2) Dynamic Method

A dynamic technique for the determination of binary vapor adsorption is illustrated in Figure 3. In this method, a vapor mixture which contains C_o g.cm^{-3} of each component is allowed to enter an adsorbent bed at a flow rate Q and the breakthrough, or penetration concentration, of each of the two components, resolved by gas chromatography, can be obtained as a function of time. Measurement of breakthrough time ($C_x/C_o = 0.01$), t_b, as a function of adsorbent bed mass for each component in a mixture then allows determination of the kinetic saturation capacity (W_e) for each component from the following equation[1,2]:

$$t_b = \frac{W_e}{C_o Q}\left[W_b - \frac{\rho_B Q}{K_v}\ln\left(C_o/C_x\right)\right] \qquad (1)$$

t_b is the time at which concentration C_x appears in the exit stream, ρ_B is the bulk density of the packed bed and K_v is a pseudo-first order adsorption rate constant.

Complications may arise if one component is adsorbed at a faster rate than the other. Under these conditions, the initial amount adsorbed for the fast adsorbing component may be greater than its saturation capacity. Displacement of the first vapor will then occur as the slower adsorbing component is adsorbed. Kinetic adsorption capacities obtained by this method for the $CHCl_3$/CCl_4 binary system are tabulated in Table 1. Total adsorption obtained by weighing the adsorbent bed (W_m) and, also, obtained from the gravimetric technique (W_g) is also tabulated for comparison.

In conclusion, both of the outlined methods can, in principle, yield equilibrium binary adsorption data. The gravimetric method, however, gives only total adsorption capacity whereas the dynamic method provides information on the adsorption capacity of each component in the mixture.
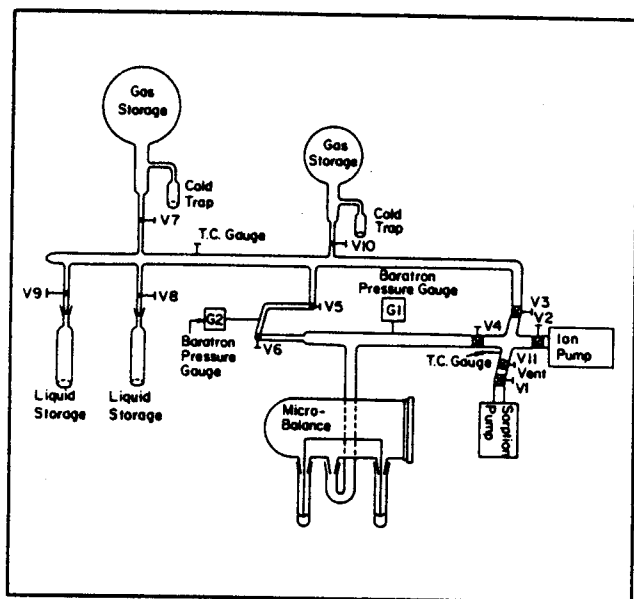
Figure 1. Gravimetric Adsorption Apparatus.

Figure 2. $CHCl_3/CCl_4$ Mixed Vapor Isotherms on BPL Activated Carbon.

References

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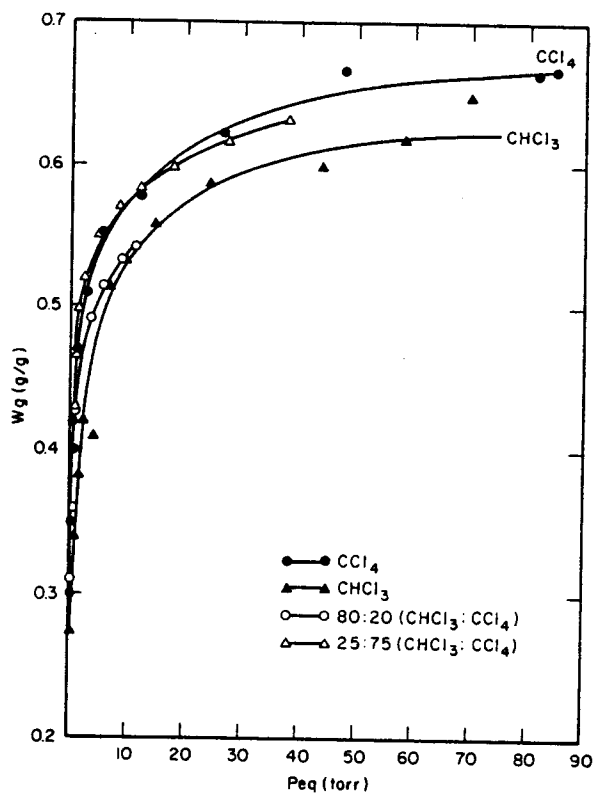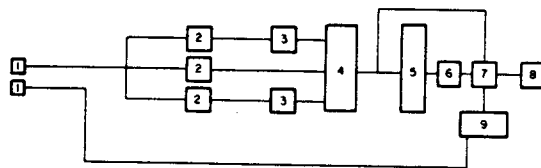7. W. K. Lewis, E. R. Gilliland, B. Chertow and B. P. Cadogan, Ind. and Eng. Chem., 42, 1326, (1950).

1. Helium serves as a diluent gas for the binary gas mixture and as a carrier gas to the chromatograph
2. Metering valves for controlling helium flow
3. 100 ml reaction flasks containing chloroform or carbon tetrachloride
4. Rotameter and mixing unit
5. Carbon bed
6. Mass flow meter
7. Gas sampling chamber
8. Vacuum Pump
9. Gas chromatograph

Figure 3. Dynamic Adsorption Apparatus.

Table 1. Equilibrium and Dynamic Adsorption Data for $CHCl_3/CCl_4$ Mixtures on BPL Activated Carbon (P_{Total} = 25 torr, Flow Rate = 400 cm^3min^{-1}, T = 25°C).

Mole Fraction N_{CHCl3} (in Vapor Phase)	W_e g/g CHCl$_3$	CCl$_4$	Total W_e g/g	W_m g/g	W_g g/g
0.00	—	0.703	0.703	0.567	0.628
0.20	0.106	0.555	0.661	0.556	0.624
0.35	0.175	0.452	0.637	0.580	0.620
0.50	0.269	0.395	0.664	0.545	0.608
0.65	0.425	0.311	0.717	0.560	0.600
0.80	0.484	0.188	0.672	0.533	0.582
1.00	0.692	—	0.692	0.505	0.570