The adsorption of Benzene-Ethylene Dichloride Mixtures on Activated Carbon

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Abstract: The single component adsorption of benzene and ethylene dichloride and also the adsorption of binary mixtures of benzene and ethylene dichloride have been studied in a small fixed isothermal bed containing activated carbon (AC). Results indicate that an empirical Langmuir isotherm fits the experimental data for single components. An extended form of the empirical Langmuir isotherm, in which the parameters are obtained from single component data, satisfactorily describes the adsorption of binary mixtures. Breakthrough curves of both components could be predicted with good precision studied. This paper analyses the adsorption behaviour of a mixture of VOCs (benzene–ethylene dichloride) on AC, due to the lack of information regarding the adsorption of mixtures.

1. Introduction
Understanding competitive adsorption of mixtures of VOCs is an important area of chemistrical engineering. It is also an effective way to protecting environment against pollution. Many studies work on single adsorption. However we are faced with mixture of VOCs, such as water pollution, air pollution etc. The study of adsorption provides information on data of the process. In this paper we obtain breakthrough curve in laboratory experiments. The single component adsorption of benzene and ethylene dichloride and also the adsorption of binary mixtures of benzene and ethylene dichloride have been studied in a small fixed isothermal bed containing activated carbon (AC). Results indicate that an empirical Langmuir isotherm fits the experimental data for single components.[1,2] An extended form of the empirical Langmuir isotherm, in which the parameters are obtained from single component data, satisfactorily describes the adsorption of binary mixtures. The potential theory of competitive adsorption is also helpful in extending the experimental data. Breakthrough curves of both components could be predicted with good precision studied. This paper analyses the adsorption behaviour of a mixture of VOCs (benzene-ethylene dichloride) on AC, due to the lack of information regarding the adsorption of mixtures.[3,4]

2. Experimental
It is possible to extract equilibrium and kinetic data for the adsorption of single component gases and also gas mixtures from experimentally observed breakthrough curves. Such experiments are conducted by passing the gaseous component or mixture through a tube (immersed in a thermostat bath) packed with the active carbons, and recording the concentration of components in the effluent emerging from the fixed bed.

2.1. Materials
The adsorbent tested in this study was CAC-1, an anthracite derived activated carbon of cylindrical form with a diameter of 0.9 mm, provided by Shanxi Xinhua Chemical Co., Ltd, China. The specific surface area of this carbon is 880 m²/g. Prior to the adsorption experiments, samples were dehydrated at 130°C for 3 hours and then purged in a dry and clean air flow overnight with the same flow rate as adsorption experiments to avoid the influence of moisture and dust on the weight of carbon bed.

The adsorbents used in the work were analytical reagent and both from Beijing Chemical Reagent Co., China.

2.2. Equipment
The complete apparatus comprised of four sections, a gas mixture preparation section, an adsorption column and a gas sampling and analysis section. The streams of benzene and ethylene dichloride vapour were generated by dynamic dilution method as follows. After cleaned and dried, compressed air was split into three parts, two of air streams partly sweeping over liquid benzene and ethylene dichloride, becoming benzene and ethylene dichloride vapour streams, and the third part meeting this stream and diluting the vapour concentration. Desired concentration can be obtained by controlling the flow rate ratio and temperature of liquid benzene. The vapour-air stream at a constant concentration and flow rate was then continuously fed to the adsorption apparatus including dynamic balance, column, and canister in this paper. The exit air stream was monitored continually by passage into an 1 cm³ gas sampling valve of the HP 6890 gas chromatograph with a flame ionization detector (FID).

2.3. Adsorbed phase calculations
The benzene and ethylene dichloride adsorption isotherms were fitted to the Langmuir isotherm and, by means of Langmuir-Freundlich (L-F) [5], the adsorption capacity for the mixture benzene-ethylene dichloride and the composition of the adsorbed phase were calculated. For single adsorption system the equation is described by the following (1) or (2)

\[ \theta = \frac{a}{a_n} = \frac{K \frac{c}{c_s}}{1 + K \frac{c}{c_s}^z} \]  

(1)

\[ \ln\left(\frac{a_n}{a} - 1\right) = -Z \ln\left(\frac{c}{c_s}\right) - \ln K \]  

(2)

The equation (3) is applied for one component of mixture system:

\[ \frac{a_i}{a_n} = \frac{K_i \left(\frac{c}{c_s}\right)^{z_i}}{1 + \sum_{i=1}^{z_i} K_i \left(\frac{c}{c_s}\right)^{z_i}} \]  

(3)

In this equation absorbance (ai) corresponds to the adsorption capacity of component (mg/g) Ki and zi are constants of component defined by Extend Langmuir-Freundlich equation:

The equation (4) is applied for mixture system.
\begin{equation}
\sum_{i=1}^{N} a_i = \sum_{i=1}^{N} K_i \left( \frac{c_i}{c_s} \right)^{z_i} \quad (4)
\end{equation}

3. Results and Discussion

3.1. Breakthrough Curve

Typical experimental breakthrough curves for benzene or ethylene dichloride single system were depicted in Fig. 2. Each experimental breakthrough curves were sigmoidal.

![Breakthrough curves](image)

Fig. 2(a) Breakthrough curves of benzene vapor of different concentrations on CAC carbon in canister. (b) Breakthrough curves of ethylene dichloride vapor of different concentrations on CAC carbon in canister (T = 298 K, L = 1 cm, v = 0.75 L·cm⁻²·min⁻¹).

3.2. Equilibrium isotherms

Equilibrium isotherms for both single component and binary mixtures were deduced from the experimental breakthrough curves. The adsorption capacities were calculated by numerical integration of the breakthrough curves. The adsorption capacity of these samples for single component and the mixture is presented in Table 1. Adsorption capacity for benzene is higher than for ethylene dichloride because the relative pressure for benzene is higher than for ethylene dichloride. In this work, we made one of the VOCs (benzene-ethylene dichloride) mixture components concentrations maintain 0.2 mg/L, another component concentration was changed. As shown in Fig.3 (a), the concentration of ethylene dichloride was fixed, with the increase concentration of benzene, the adsorption capacity of ethylene dichloride decreased, the adsorption capacity of benzene increased. As shown in Fig.3 (b), the concentration of benzene was fixed, with the increase concentration of ethylene dichloride, the adsorption capacity of ethylene dichloride increased, the adsorption capacity of benzene decreased. Thus, the adsorption capacity was related with components concentration, the existence of competition component due to adsorption capacity decreased.

**Table 1.** Experimental adsorption capacities for the single component system and mixture system of benzene–ethylene dichloride.

| Sample Type   | Component 1 | Component 2 |
|---------------|-------------|-------------|
| Single Sample | \(c_0\)     | \(a_0\)     |
| Mixture Sample| \(c_{01}\)  | \(a_{01}\)  | \(c_{02}\) | \(a_{02}\) |
Table 2. Comparison of theoretical parameter K and Z for the single component system and mixture system of benzene–ethylene dichloride.

| Component | System   | K     | Z     | ln(K/Z) |
|-----------|----------|-------|-------|---------|
| benzene   | single   | 6.26  | 0.43  | 2.68    |
|           | mixture  | 9.04  | 0.48  | 2.94    |
| ethylene  | single   | 10.0  | 0.55  | 2.90    |
The parameter $Z$ of mixture system of benzene-ethylene dichloride system was same as the single system, so we considered it was constant. Extend Langmuir-Freundlich equation was simplified. The experiment data demonstrate the agreement between the theoretical and experimental isotherms of mixture system.

4. Conclusions

Adsorption of mixtures of benzene and ethylene dichloride on AC was analysed to determine the effect of concentration. Adsorption capacity for benzene is higher than ethylene dichloride. Adsorption of ethylene dichloride in binary system decreased because the increased concentration of benzene. The adsorption data shows that these activated carbons have very high adsorption capacities for the mixtures.

Langmuir-Freundlich theory has been applied to equilibrium data for single benzene and ethylene dichloride adsorption isotherms to predict the binary equilibrium. This paper found there were same Z parameter in either single adsorption system or mixture system, but parameter $K$ is different. This study shows good agreement between the experimental and the theory in single system, but Langmuir-Freundlich equation must be revised in binary system. Attempts are made to improve Langmuir-Freundlich equation by applying different parameter $K$.

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