# Dynamics of Multicomponent Adsorption in Fixed Bed Carbon Columns

Imre Zwiebel
Arizona State University

and

Joseph A. Rehrmann
Aberdeen Proving Ground

The dynamics of fixed bed adsorption columns with multicomponent gas feed streams is being investigated. Thus far feed streams consisting of an air carrier gas with one and two adsorbing components have been studied; and the plans are to extend the series to three and four adsorbate species.

The objective of the study is to develop relationships for the evaluation of mass transfer coefficients for multicomponent adsorption operations. The best available correlations are cosmetic modifications of the relationship developed over fifty years ago by Chilton and Colburn (1935) for $CO_2$ absorption in water.

Michaels (1952) proposed a method whereby an averaged mass transfer coefficient could be evaluated from breakthrough data. This averaging encompassed the entire composition range ( 0 to $C_o$ ) and adsorbent loadings range (0 to $W_o$) along the width of the mass transfer zone, and also covered moderate variation of the gas velocity and temperature, which depend upon the operating conditions. Even so, it can be shown that the use of these averaged mass transfer coefficients are satisfactory for systems which exhibit constant pattern behavior, that is, if after formation the length and shape of the mass transfer zone remain unchanged.

Theoretically only systems which can be described by a linear isotherm could exhibit constant pattern behavior. However, in practice the mass transfer zone remains unchanged when the equilibrium is convex to the loading axis and the adsorption column is relatively long. In these cases the mass transfer zone remains constant because of two cancelling mechanisms, the sharpening due to the favorable isotherm is countered by the axial dispersion of the adsorbate molecules along the steep concentration profile.

The most immediate objective is to establish criteria by which the averaged single component mass transfer coefficients can be correlated to provide suitable multicomponent mass transfer coefficients. Therefore, the single component coefficients were calculated from the single component breakthrough curves, and the multicomponent coefficients were calculated from the multicomponent breakthrough curves. The appropriate correlation between the two sets of coefficients was derived. At this point, only two component data are available, but experiments are planned so that we can generalize to multicomponent systems.

## Experimental

An apparatus was built to experimentally measure the breakthrough curves of each of the adsorbing species. The carrier gas was bubbled through saturators containing the liquid adsorbates; separate saturators in parallel were used for each of the adsorbates. The degree of saturation was controlled by

adjusting the saturator temperature. The saturator effluents were analyzed by thermal conductivity measurements; these data were transmitted to the computer which monitored the column feed composition. If necessary, by way of D/A coupling, the flow rate of makeup gas and/or the temperature of each saturator was adjusted to maintain the pre-established constant feed composition.

The feed mixture was fed to the column as a step input function of the adsorbate compositions. The column effluent was sampled, 30 s.cc/min samples to each detector. Whenever possible, separate detectors were used to determine the composition of each component (i.e., the Electron Capture Detector (ECD) was specific to dichloromethane). Otherwise, by appropriate calibration the signals were broken down to provide the composition of each component (i.e., the Flame Ionization Detector (FID) measures total hydrocarbons, but after proper subtraction of the ECD signal the remainder corresponds to the benzene composition). The signals from each detector was transmitted to the computer for the necessary data analysis and data output.

The measured curves were used to evaluate the mass transfer coefficients according to the method outlined by Michaels. Particular emphasis was focused in this initial study on strongly adsorbed species which can be described by a favorable isotherm and whose breakthrough behavior would closely approximate the constant pattern model. With activated carbon as the adsorbent the vapors of organic liquids, like benzene and dichloromethane, were chosen as the initial adsorbates.

## Results

Both single component and two component experiments were run at fixed compositions and fixed gas flowrate (i.e., same superficial gas velocity) to determine the breakthrough behavior as a function of bed length (weight of adsorbent). The breakthrough times were found to be a linear function of bed size, and the width of the breakthrough curves were found to be independent of bed size.

Experiments were also run at different velocities and, as expected, the breakthrough times were found to be a logarithmic function of the velocity.

Two component experiments were run at a fixed gas flow rate (and gas velocity) at various compositions of the two adsorbing species. The following observations were made:

1. Benzene was the more strongly adsorbed component; thus the dichloromethane always broke through first.
2. The breakthrough times of both components decreased as the composition of either component was increased.
3. The dichloromethane exit composition overshot the inlet composition; the stronger adsorbed benzene displaced some of the dichloromethane.
4. The dichloromethane overshot peak composition increased with increasing benzene composition but decreased with increasing dichloromethane compositions; substantiating the competitive interaction between the two species.
5. The time at which the dichloromethane overshoot peak composition occured was found to be independent of the dichloromethane composition but decreased with increasing benzene feed compositions; verifying the greater affinity of the carbon for the benzene.

The multicomponent mass transfer coefficients, as a first approximation, were found to be composition weighted functions of the single component coefficients.

## References

Chilton, T. H. and A. P. Colburn, "Distillation and Absorption in Packed Columns", Ind. Eng. Chem., 27, 255 (1935).

Michaels, A. S., "Simplified Method of Interpreting Kinetic Data in Fixed Bed Ion Exchange", Ind. Eng. Chem., 44, 1922 (1952).