Effect of Water on the Vapour Phase Adsorption of Organic Solvents

Michael HARASEK, Harald KALLINGER and Anton FRIEDL

Institute of Chemical Engineering, Vienna University of Technology
Getreidemarkt 9/1662, A-1060 Vienna, Austria
E-Mail: mharasek@mail.zserv.tuwien.ac.at
http://therm.vt.tuwien.ac.at

Introduction

Activated carbon (AC) adsorber columns are widely used to clean waste gas streams from volatile organic compounds (VOC) or to reduce VOC concentration peaks before entering a biofilter [1]. Unfortunately, water vapour is frequently present in the gas stream as well and may affect the adsorption of the VOC significantly.
Consequently, the knowledge of multi-component adsorption equilibria is of high importance for the design of adsorption processes. The activated carbon used for such purposes is selective for VOCs –exhibiting a type I adsorption isotherm following the classification according to Brunauer [2] – and shows low water vapour adsorption until capillary condensation occurs, leading to the typically S-shaped type V adsorption isotherm. However, in case of simultaneous adsorption of water and organic compounds a straightforward approach to predict the binary adsorption equilibrium is difficult because of the fundamental difference in the adsorption mechanism of the two species and the complex interactions in the adsorbed phase.

Experimental

Experimentally determined gas phase adsorption equilibria are presented for two binary systems on activated carbon (BET surface area: >1250 m²/g): ethyl acetate / water and toluene / water. Experiments were conducted by exposing an activated carbon sample to a gas stream with constant adsorptive concentration. A microbalance / mass spectrometry system was used to determine the individual amounts of water and VOC adsorbed (Fig. 1, 3). To increase accuracy of results, temperature controlled desorption was applied to determine the amount of VOC adsorbed (Fig. 2). A Dubinin-Radushkevic isotherm describes VOC adsorption very well; for water, a modified Dubinin-Radushkevic approach was used (Fig.4) [3].

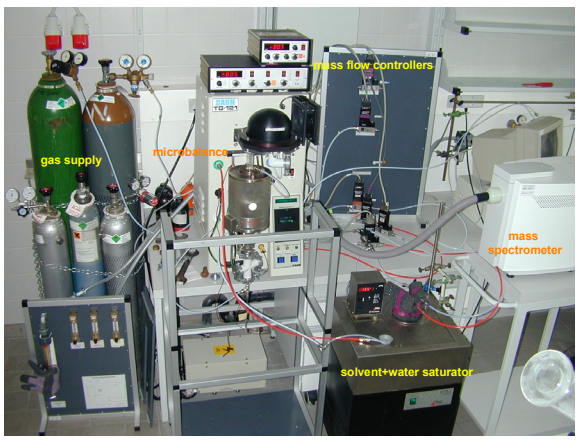

Figure 1: Experimental apparatus.

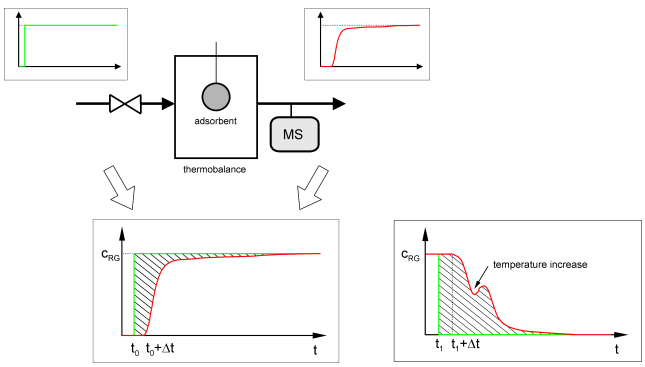

Figure 2: Isotherm from adsorption measurement (left). Isotherm from temperature programmed desorption (right).

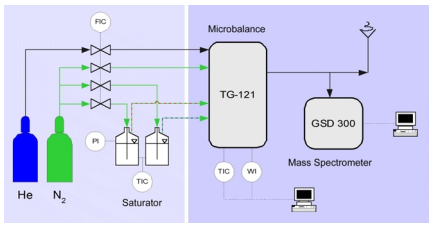

Figure 3: Schematic diagram.

Results and Conclusions

There is a fundamental difference in adsorption equilibrium between the partially miscible ethyl acetate – water and the immiscible toluene – water system. Results show, that for the partially miscible ethyl acetate – water system the influence of water on the adsorption behaviour of ethyl acetate is strong and inhibits ethyl acetate adsorption, interaction between ethyl acetate and water also in the adsorbed phase is expected. At low ethyl acetate concentrations the adsorption of water is enhanced so that even more water can be adsorbed compared to the pure water isotherm (Fig. 5a,b). It is believed that the adsorbed ethyl acetate molecules act as secondary adsorption sites for water adsorption by forming hydrogen bonds with the water molecules [4].
The effect of water on the adsorption capacity of toluene is significantly lower. Because of the immiscibility of the toluene - water system and the higher attraction forces of toluene on AC, no significant reduction of the adsorption capacity for toluene was detected. No capillary condensation of water was noticed in the investigated range. Adversely, toluene reduces water adsorption significantly (Fig. 6a,b) [4].
In conclusion, for typical AC adsorber applications (e.g. VOC buffering for biofilters) it could be shown that water immiscible VOCs can be removed well from humidified gas streams even at low VOC concentrations without the risk of adsorbing simultaneously high amounts of water. The adsorption of partially water-miscible VOCs is sensitive to humidity in the gas stream.

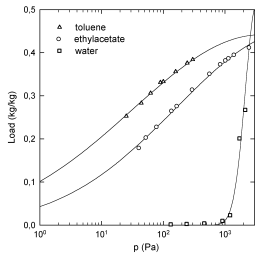

Figure 4: Single component adsorption onto activated carbon (as specified).

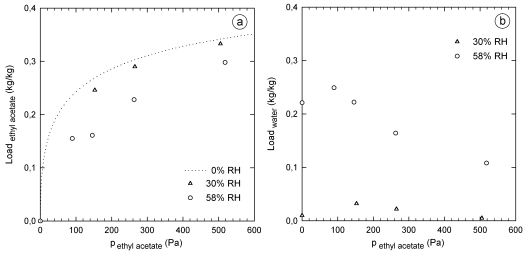

Figure 5a,b: Adsorption isotherms for ethyl acetate – water at 298 K. Dotted line shows pure ethyl acetate isotherm.

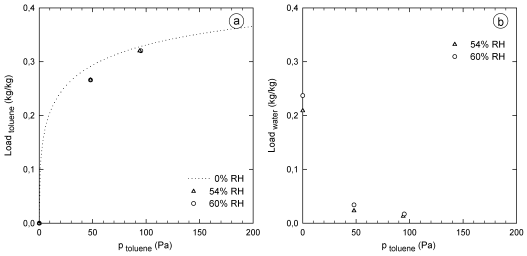

Figure 6a,b: Adsorption isotherms for toluene – water at 298 K. Dotted line shows pure toluene isotherm.

References

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TU WIEN
Technische Universität Wien
Vienna University of Technology
Institute of Chemical Engineering
Thermal Process Engineering & Simulation