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Adsorption and Adsorptive Separations: A Review and Bibliographical Update (1994)

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Abstract. This paper provides a review of the 1994 journal literature and complete bibliography concerned with adsorptive separations. The references are taken from the 45 most important chemical engineering journals. This paper provides an update to the literature as provided in previous bibliographic papers (Ray 1990; 1991; 1995). References for membranes and membrane-type separations (for 1992–1993) were the subject of a separate bibliographic paper (Ray 1994), due to the number of papers now published on this topic each year. A review and bibliography paper covering 1994 for membranes has been submitted for publication. Bibliographic papers covering traditional unit operations (Ray 1992; 1993; 1994; 1994) and supercritical extraction (Ray 1994) have been published. A bibliography of the chemical engineering journal literature from 1967–1988 has been published by the author (Ray 1990), and can provide access to a wider range of topics. A complete bibliographic listing of the chemical engineering journal literature from 1989 to 1994 (with subsequent six-monthly updates) is available on a CD-ROM database (Published by Royal Melbourne Institute of Technology) and full details can be obtained from the author.

Keywords: applications, bibliography, processes

The papers reviewed here have been divided into the following subject groups:

1.1. Theory
1.2. Design Data
1.3. Adsorbents
1.4. PSA and Cyclic Systems, and Applications
1.5. Liquid-Phase Adsorption
1.6. Ion Exchange, Chromatography, etc.

Some articles which were not reviewed are also included to provide a complete bibliography.

1.1. Theory

Akman, U. and Sunol, A.K., Equilibrium theory for exsorption: A gas-liquid-adsorbent mass-transfer operation, Chem. Eng. Sci., 49(21), 3555–3563 (1994). An equilibrium theory for three-phase (gas-liquid-adsorbent) mass-transfer has been established based on the distributed-parameter models of the system.

Anand, N., Manoja, B.G.R., and Gupta, A.K., Kinetics of adsorption on biporous solids, for a system with rectangular equilibrium, reanalysed, Chem. Eng. Sci., 49(19), 3277–3290 (1994). Mass transfer equations were solved numerically using a finite-difference technique. There are three distinct adsorption regions: (a) outer shell of completely (or almost) saturated microspheres; (b) adsorption shell of microspheres where adsorption is taking place at a given moment; (c) core of microspheres yet to be exposed to the adsorbate. Defined a dimensionless parameter; the rate of adsorption may be much higher than that predicted by the shrinking core model.

Annesini, M.C., Giona, M., and Gironi, F., Continuous model for complex mixture adsorption, Ind. Eng. Chem. Res., 33(11), 2764–2770 (1994).

Bakaev, V.A. and Steele, W.A., The characteristic curve in physical adsorption, Adsorpt. Sci. Technol., 10, 123–136 (1994). Traces the concept of the characteristic curve in physical adsorption and the rule of its temperature invariance, also the theory of volume filling of micropores, and the theory of adsorption on heterogeneous surfaces.

Carrott, P.J.M., On the Dubinin-Serpinski equation, Adsorpt. Sci. Technol., 10, 63–74 (1994). This simple model accounts for many of the principal factors involved in the formation of an adsorbed water phase on carbon surfaces. The limited results suggest that the D-S equation may be able to describe the characterisation of both the functionality and microstructure of carbon adsorbents.

Chen, A. and Hirtzel, C.S., Monte Carlo simulation of multicomponent system by Marco State Markov Chain Model (MSMCM), Sep. Technol., 4(3), 167–173 (1994). The MSMCM model is used in developing parallel Monte Carlo simulation schemes to dramatically reduce computer simulation time. It is used here to study the adsorption of a mixture of oxygen and nitrogen in zeolite 5A.

Croft, D.T. and Levan, M.D., Periodic states of adsorption cycles. I. Direct determination and stability, Chem. Eng. Sci., 49(11), 1821–1829 (1994). Method is compared to a literature PSA model and shows that for the constrained case, the first and only periodic state found satisfies a design specification.

Croft, D.T. and Levan, M.D., Periodic states of adsorption cycles. II. Solution spaces and multiplicity, Chem. Eng. Sci., 49(11), 1831–1841 (1994). The method allows location of both stable and unstable periodic states and determines the manner in which a cycle loses stability. Compared to literature models of PSA and TSA, mapping the solution spaces showed different types of multiplicity all of which have constraints such as a control scheme in the model.

Dunne, J. and Myers, A.L., Adsorption of gas mixtures in micropores: Effect of difference in size of adsorbate molecules, Chem. Eng. Sci., 49(17), 2941–2951 (1994). Adsorbed solutions of molecules of unequal size (CCl_2F_2 and CO_2 on activated carbon) show negative deviation from ideal mixing, and the size effect was studied by molecular simulation. The partial exclusion effect of the larger molecule is calculated from the cavity radius and the molecular diameters of the adsorbates.

Filippov, L.K., Multicomponent non-isothermal adsorption dynamics, Chem. Eng. Commun., 127, 75–107 (1994). Major review of the theoretical models for non-isothermal kinetics and dynamics of multicomponent adsorption. Model classifications are included, and model equations accounting for all major qualitative physicochemical features of heat and mass transfer through interfaces and in the intergranular space of porous media. A very useful summary paper.

Filippov, L.K., Coherent and incoherent frontal patterns of multicomponent adsorption dynamics for variable linear fluid velocity in the fixed bed. I. Frontal patterns for linear adsorption isotherms, Chem. Eng. Sci., 49(20), 3499–3509 (1994). The influence of the dispersive factors (kinetics and longitudinal dispersion) on the nature of the concentration distributions is considered. For different nonequilibrium theoretical models, a simple formula to calculate the mass transfer zone is derived for the coherent constant patterns. It is shown that the dispersive factors can convert coherent patterns into incoherent ones.

Filippov, L.K., Study of adsorption of polymers on particulate surfaces by impregnation, Chem. Eng. Commun., 129, 1–18 (1994).

Gomes, V.G. and Fuller, O.M., Fixed-bed adsorber dynamics in binary physisorption-diffusion, Can. J. Chem. Eng., 72(4), 622–630 (1994). Reactions carried out at close to the equilibrium vapour pressure of the participating species involve physisorption on the catalyst surface, e.g. propene metathesis over rhenium oxide/gamma-alumina catalyst at room temperature. The model equations were solved by orthogonal collocation within the method of lines.

Harriott, G.M., Memory-integral mass-transfer models for adsorption process simulation (errata), AIChE J., 40(6), 956 (1994).

Hassan, M.M., Rahman, A.K.M.S., and Loughlin, K.F., Numerical simulation of unsteady continuous countercurrent adsorption system with nonlinear adsorption isotherm, Sep. Technol., 4(1), 15–26 (1994). Theoretical dispersed plug-flow model including a mass transfer resistance represented by a linear driving force approximation for unsteady-state continuous countercurrent adsorption systems with nonlinear equilibrium isotherms. Shows that optimal choice of bed length, feed and eluent flow rates, and switch times must be adapted as nonlinearity changes. Results lie between the 'pore diffusion' and 'equilibrium' models.

Hu, X., Do, D.D., and Rao, G.N., Experimental concentration dependence of surface diffusivity of hydrocarbons in activated carbon, Chem. Eng. Sci., 49(13), 2145–2152 (1994). A differential adsorption bed is operated so that the adsorbed concentration is nearly constant during the adsorption process, and surface diffusivity is determined using a pore and surface diffusion model. A much stronger concentration dependence of surface diffusivity was observed than is predicted by the Darken equation.

Jin, X., Talbot, J., and Wang, N.H.L., Analysis of steric hindrance effects on adsorption kinetics and equilibria, AIChE J., 40(10), 1685–1696 (1994). Extension of the random adsorption concept for irreversible adsorption was used to analyze reversible adsorption on a continuous surface and a randon site surface. Simulation results show that the model can correlate experimental data, and predict the physical significance of the adsorption parameters such as the maximum adsorption capacity.

Jordi, R.G. and Do, D.D., Analysis of the frequency response method applied to non-isothermal sorption studies, Chem. Eng. Sci., 49(7), 957–979 (1994). Finite rates of heat transfer from the gas phase to the environment, and from the sorbent particle to the gas phase, are shown to influence significantly the in-phase and out-of-phase components of the gas pressure response.

Kaminsky, R.D. and Monson, P.A., A simple mean field theory of adsorption in disordered porous materials, Chem. Eng. Sci., 49(17), 2967–2977 (1994). Theory applies to fluids in heterogeneous solids (e.g. silica gel) based on a molecular model which treats the solid as a matrix of particles with a predefined structure. It was compared to experimental results for single and binary adsorption of argon-methane and ethane-methane mixtures.

Mazzotti, M., Storti, G., and Morbidelli, M., Robust design of countercurrent adsorption separation processes: 2. Multicomponent systems, AIChE J., 40(11), 1825–1842 (1994). Developed a procedure for optimal and robust design using equilibrium theory, where adsorption equilibria are described through the constant selectivity stoichiometric model, neglecting mass-transfer resistances and axial dispersion. An approximate shortcut method predicts explicit and reliable relationships for estimating the boundaries of the exact region where complete separation occurs. Can also analyze the role of the desorbent in determining the separation performance.

Mazzotti, M., Storti, G., and Morbidelli, M., Shock layer analysis in multicomponent chromatography and countercurrent adsorption, Chem. Eng. Sci., 49(9), 1337–1355 (1994). Theory presented for fixed-bed and countercurrent columns with Langmuir-type adsorption isotherms. Two models were developed to describe adsorption-diffusion processes in solid particles, namely the solid diffusion model and pore diffusion model. Theory agrees well with numerical results except when strong interactions occur between neighboring shocks.

Mendes, A.M.M., Costa, C.A.V., and Rodrigues, A.E., Linear driving force approximation for diffusion in spherical adsorbents with binary non-linear adsorption, Gas Sep. Purif., 8(4), 229–236 (1994). Applies to cyclic steady-state for pore diffusion in the presence of binary Langmuirian adsorption under a periodic boundary condition in composition, total pressure, or both. Uses two parameters, one for each solute, calculated for a square wave with the same period and a second pair of parameters that correct the approximation for the phase lags. Error is less than 5% for equilibrium, diffusion and frequency conditions in the range of most practical systems. Can also be used for homogeneous diffusion.

Miyahara, M., Kato, M., and Okazaki, M., Liquid-phase capillary condensation and adsorption isotherm, AIChE J., 40(9), 1549–1557 (1994). The separation of a solute (as liquid) into small pores by capillary effect, providing a relation between the concentration and a critical radius of the phase separation. Also able to estimate liquid-phase adsorption isotherms of adsorbates with limited solubility from pore-size distribution of solids.

Rao, G.N., Hu, X., and Do, D.D., Multicomponent sorption of hydrocarbons in activated carbon: Simultaneous desorption and displacement, Gas Sep. Purif., 8(2), 67–76 (1994). Comparison of experimental data for ethane-propane with a macropore, surface and micropore diffusion (MSMD) model, using the ideal adsorbed solution theory (IAST) with the Unilan isotherm equation.

Rozwadowski, M., Wloch, J., Kornatowski, J., and Erdmann, K., Equation of the sorption isotherm on zeolite Y including heterogeneity of the sorbent: A novel modification, Adsorpt. Sci. Technol., 10,

241–253 (1994). An equation for water vapour adsorption which includes the size distribution of the sorbent micropores, also enables accurate calculation of the total micropore volume. Sodium counterions have a significant effect on the water-vapour sorption.

Serpinski, V.V. and Jakubov, T.S., Dubinin-Radushkevich equation as the equation for the excess adsorption isotherm, Adsorpt. Sci. Technol., 10, 85–92 (1994). The D-R equation describes the experimental excess adsorption isotherm excellently over a very wide range of gas equilibrium pressures. An algorithm allows conversion of measurable values of excess adsorption to absolute values.

Shah, D.B., A course on the fundamentals of adsorption, Chem. Eng. Educ., 28(4), 250–253 (1994). Details of a graduate course in adsorption, dealing mainly with molecular sieves.

Shen, C.M. and Worek, W.M., Cosorption characteristics of solid adsorbents, Int. J. Heat Mass Transfer, 37(14), 2123–2129 (1994). The cosorption isothermal dynamic behaviors on activated carbon (AC), silica gel (SG), and molecular sieve (ZMS) were simulated. The simultaneous presence of water vapor and CO_2 in process air decreases the adsorption capacities on these adsorbents. The roll-over effect, which occurs when the outlet concentration is higher than the inlet concentration, appears in the breakthrough curves of CO_2. This effect is due to faster diffusion and a lower affinity of CO_2 than water vapor for the adsorbents. This effect is more pronounced for the cosorption process on ZMS than on AC or SG.

Sircar, S., Non-isothermal differential adsorption kinetics for binary gas mixture, Ind. Eng. Chem. Res., 33(6), 1585–1592 (1994).

Stoeckli, F., Dubinin's theory for the volume filling of micropores: An historical approach, Adsorpt. Sci. Technol., 10, 3–16 (1994). New approach includes the enthalpy of immersion into water, a thermodynamic consequence of Dubinin's theory. The adsorption of water by microporous carbons (corresponding to a type V isotherm) can also be described by the equation of Dubinin and Astakhov.

Sun, L.M., Meunier, F., Grenier, P. and Ruthven, D.M., Frequency response for nonisothermal adsorption in biporous pellets, Chem. Eng. Sci., 49(3), 373–381 (1994). Theoretical analysis including heat and mass transfer resistances in both micropores and macropores.

Tan, H.K.S., Analysis of cyclic fixed bed sorption processes for second-order irreversible kinetics, Chem. Eng. Sci., 49(8), 1277–1285 (1994). Process performance is shown to depend upon four cyclic design parameters, and sorption effectiveness is independent of the direction of regeneration.

Tolmachev, A.M., The characteristic curve method in adsorption, Adsorpt. Sci. Technol., 10, 155–164 (1994). The method enables a priori calculations of adsorption equilibria on microporous adsorbents in single and multicomponent systems over a wide range of temperature and equilibrium phase compositions. Requires only very limited 'basic' experimental information.

Van Tassel, P.R., Davis, H.T. and McCormick, A.V., New lattice model for adsorption of small molecules in zeolite micropores, AIChE J., 40(6), 925–934 (1994). Adsorption assumed to occur onto a 3-D polyhedral lattice, and both the energy and entropy of the lattice sites are accounted for in a statistical mechanics approach. Energetic interactions and entropic interactions are taken into account. The model was applied to xenon and methane adsorbed in idealized zeolite NaA, and it quantitatively predicted the simulated isotherm over the entire pressure range.

Van Tassel, P.R., Somers, S.A., Davis, H.T., and McCormick, A.V., Lattice model and simulation of dynamics of adsorbate motion in zeolites, Chem. Eng. Sci., 49(17), 2979–2989 (1994). Examines the effect of the structure and energetics of the adsorption site lattice on the mobility of small molecules in cage-like micropores using Monte Carlo lattice dynamics simulations. Also compared to molecular dynamics simulations for methane adsorbed in zeolite-A showing qualitative agreement between the two approaches.

Vega, L.F., Panagiotopoulos, A.Z., and Gubbins, K.E., Chemical potentials and adsorption isotherms of polymers confined between parallel plates, Chem. Eng. Sci., 49(17), 2921–2929 (1994). Results of Monte Carlo simulations of chains confined in a very narrow slit, in the limit of strongly attractive walls. A strong bridging effect is observed due to this strong attraction.

von Gemmingen, U., A new approach to adsorption isotherms (corrigendum), Gas Sep. Purif., 8(4), 272 (1994).

Vortmeyer, D., Giese, M., and Lingg, G., Extension of the van Deemter equation to nonlinear isotherms of the Langmuir type, Chem. Eng. Sci., 49(16), 2593–

2598 (1994). The van Deemter equation included a generalized dispersion term which includes the simulation of zone spreading by mass transfer. This paper shows that equivalence between one- and two-phase models is also obtained for nonlinear Langmuir isotherms, if linear driving force conditions prevail and intraparticle diffusion is rate controlling.

Wei, J., Nonlinear phenomena in zeolite diffusion and reaction, Ind. Eng. Chem. Res., 33(10), 2467–2472 (1994).

Yao, C. and Tien, C., Approximate solution of intraparticle diffusion equations and their application to continuous-flow stirred tank and fixed-bed adsorption calculations, Sep. Technol., 4(2), 67–80 (1994). Application of two approximate uptake rate expressions (for batch calculations) for spherical adsorbent pellets in continuous-flow stirred tank and fixed-bed adsorption processes. Both expressions provide improvement over the conventional linear driving force model, and the accuracy depends upon the type of driving force for interphase mass transfer that is present in a particular situation.

Zhou, C., Hall, F., and Gasem, K.A.M., Predicting gas adsorption using two-dimensional equations of state, Ind. Eng. Chem. Res., 33(5), 1280–1289 (1994).

1.2. Design Data

Afzal, A., Khan, M., and Ahmad, H., Kinetics of the sorption of organic vapours in chromatographic silica gel, Adsorpt. Sci. Technol., 11(2), 113–122 (1994). Adsorption of ethyl methyl ketone, methyl acetate, methyl alcohol, diethyl ether, acetone, and acetaldehyde between 273–297 K and a vacuum of 10^{-4} to 10^{-5} Torr.

Aguayo, A.T., Gayubo, A.G., Erena, J., Olazar, M., Arandes, J.M., and Bilbao, J., Isotherms of chemical adsorption of bases on solid catalysts for acidity measurement, J. Chem. Technol. Biotechnol., 60(2), 141–146 (1994). Measurement of adsorption equilibrium constants of the bases and the total mass of base adsorbed at 200°C are proposed as reproducible indices of average acidity strength and of total acidity of the solid, respectively. The bases (ammonia, *n*-butylamine, tert-butylamine, pyridine) adsorbed from the gas phase onto solid acidic catalysts (silica-alumina and zeolite catalysts and a silica gel).

Anthony, R.G., Dosch, R.G., and Philip, C.V., Use of silicotitanates for removing cesium and strontium from defense waste, Ind. Eng. Chem. Res., 33(11), 2702–2705 (1994).

Biernat, J.F., Konieczka, P., and Izatt, R.M., Complexing and chelating agents immobilized on silica gel and related material and their application for sorption of inorganic species, Sep. Purif. Methods, 23(2), 77–120 (1994).

Butani, M.M. and Kumari, R., Surface and charge characteristics of the oxide/solution interface towards chromium(VI) sorption, Adsorpt. Sci. Technol., 11(3), 145–154 (1994).

Cal, M.P., Larson, S.M., and Rood, M.J., Experimental and modeled results describing the adsorption of acetone and benzene onto activated carbon fibers, Environ. Prog., 13(1), 26–30 (1994). Experimental data and model results show that activated carbon fibres have potential as an adsorbent for removing low concentrations of VOCs from indoor air.

Calleja, G., Jimenez, A., Pau, J., Dominguez, L., and Perez, P., Multicomponent adsorption equilibrium of ethylene, propane, propylene and carbon dioxide on 13X-zeolite, Gas Sep. Purif., 8(4), 247–256 (1994). Experimental adsorption isotherms for binary, ternary and quaternary mixtures at 293 K; data were fitted to three theoretical models.

Chen, Y.D., Yang, R.T., and Uawithya, P., Diffusion of oxygen, nitrogen and their mixtures in carbon molecular sieve, AIChE J., 40(4), 577–585 (1994). Diffusivities measured under conditions used for kinetic separation of air by adsorption (elevated pressures). In binary diffusion, codiffusion enhances fluxes for both components whereas counterdiffusion has the opposite effects. For both cases, the effects are significantly more pronounced for the fast diffusing component. Multicomponent diffusivities can be predicted from pure-component data for concentration-dependent diffusivities and diffusional activation energies.

Choudhary, V.R., Mayadevi, S., and Kamble, K.R., Adsorption of oxygen and nitrogen on AlPO(4)-5 and SaPO-5 at moderate pressures using a novel adsorption/desorption method, Ind. Eng. Chem. Res., 33(5), 1319–1323 (1994).

Do, H.D. and Do, D.D., Structural heterogeneity in the equilibrium data for hydrocarbons and carbon oxides on activated carbons, Gas Sep. Purif., 8(2), 77–93 (1994). Comparison of experimental data to a theory developed to investigate the structural heterogeneity

(characterized by micropore size distribution) in the adsorption equilibria for gas-solid systems.

El-Shoubary, Y., Woodmansee, D.E., and Shilling, N.Z., Sorption and desorption of contaminants from different host matrices, Environ. Prog., 13(1), 37–44 (1994). Using air and nitrogen atmospheres to determine the effect of surface area on contaminant sorption and desorption for sand, oil and sand, and PCB mixtures. As surface area increases, the contaminant concentration increases. For desorption, the onset temperature decreases as the surface area increases. However, this phenomenon was reversed when the surface area included pore structure.

Fitch, F.R., Bulow, M., and LaCava, A.I., Investigation of the mechanism for the separation of nitrogen-oxygen mixtures on carbon molecular sieves, Gas Sep. Purif., 8(1), 45–51 (1994). Experimental data suggests the existence of a surface barrier in the pore mouths of slit-like micropores for the samples. This conclusion is supported by canonical and Monte Carlo simulations.

Foeth, F., Andersson, M., Bosch, H., Aly, G., and Reith, T., Separation of dilute carbon dioxide/methane mixtures by adsorption on activated carbon, Sep. Sci. Technol., 29(1), 93–118 (1994). Experimental breakthrough curves obtained for both adsorption and desorption processes using mixtures of one or two adsorbable components and one non-adsorbable. A parametric study was conducted to determine the influence of temperature, inlet partial pressure, and superficial velocity on the performance of the adsorption process.

Golden, T.C. and Sircar, S., Equilibrium and kinetics of adsorption of freon-12 at infinite dilution, AIChE J., 40(6), 935–943 (1994). Coadsorption of the bulk carrier gas can severely reduce the equilibrium adsorption capacity and adsorptive mass-transfer coefficient of strongly adsorbed Freon-12. The mass transfer was dominated by surface diffusion into the pores of the activated carbon.

Green, T.K. and Selby, T.D., Pyridine sorption isotherms of Argonne premium coals: Dual-mode sorption and coal microporosity, Energy Fuels, 8(1), 213–218 (1994). Results suggest that pyridine extraction of the coals creates new micropores, and with o-alkylation the added alkyl groups occupy micropores in the structure.

Hassan, N.M., Al-Ameeri, R.S., and Oweysi, F., Separation of *n*-paraffins from kerosene-range feedstock by adsorption on fixed-bed urea, Sep. Sci. Technol., 29(3), 401–414 (1994). Experimental results showed that n-paraffin molecules from unified heavy kerosene were more strongly adsorbed than those from straight-run kerosene or naphtha-kerosene blend, indicating that adsorption increased with the molecular length of the hydrocarbon.

Hu, X. and Do, D.D., Effect of energy distribution shape on the sorption equilibrium and dynamics of sulphur dioxide in activated carbon, Chem. Eng. Sci., 49(6), 919–923 (1994). Experimental data was used to test a heterogeneous pore and surface diffusion model and to study the effect of energy distribution shape on the sorption dynamics.

Hu, X., King, B., and Do, D.D., Ternary adsorption kinetics of gases in activated carbon, Gas Sep. Purif., 8(3), 175–186 (1994). Ternary adsorption kinetic experiments of ethane, propane and *n*-butane in activated carbon at various temperatures, concentrations and particle sizes. Data was compared to the predictions of a multicomponent heterogeneous macropore, surface and micropore diffusion model, using only single-component equilibrium and mass transfer parameters.

Hu, X., King, B., and Do, D.D., Ternary desorption and displacement kinetics of gases in activated carbon, Gas Sep. Purif., 8(3), 187–190 (1994). Experimental data for ternary systems of ethane, propane and n-butane at various temperatures, particle sizes and shapes.

Huang, R.T., Chen, T.L., and Weng, H.S., Adsorption of *o*-cresol and benzoic acid in an adsorber packed with an ion-exchange resin: A comparative study of diffusional models, Sep. Sci. Technol., 29(15), 2019–2033 (1994). Use of solid- and pore-diffusion models to simulate adsorption in a fixed bed with anion-exchange resin. For linear isotherm (e.g. o-cresol), both models gave good areement with experimental breakthrough data. The solid-diffusion model gave better agreement with a favourable isotherm (e.g. benzoic acid). Several other factors need to be considered when selecting a model, e.g. type of adsorbent, equilibrium data, and concentration dependence of the intraparticle diffusivity.

Huang, Y.H., Johnson, J.W., Liapis, A.I., and Crosser, O.K., Experimental determination of the binary equilibrium adsorption and desorption of propane-propylene mixtures on 13X sieves by a differential sorption bed system and investigation of their equilibrium expressions, Sep. Technol., 4(3), 156–166

(1994). The Toth equation showed very good correlation for the experimental single-component data. For binary mixtures where propylene is preferentially adsorbed, several expressions were tested but none provided satisfactory prediction of the experimental results.

Hwang, K.S. and Lee, W.K., The adsorption and desorption breakthrough behavior of carbon monoxide and carbon dioxide on activated carbon: Effect of total pressure and pressure-dependent mass transfer coefficients, Sep. Sci. Technol., 29(14), 1857–1892 (1994).

Iwai, Y., Uchida, H., and Mori, Y., Separation of isomeric dimethylnaphthalene mixture in supercritical carbon dioxide by using zeolite, Ind. Eng. Chem. Res., 33(9), 2157–2160 (1994).

Kabay, N., Preparation of amidoxime-fiber adsorbents based on poly(methacrylonitrile) for recovery of uranium from seawater, Sep. Sci. Technol., 29(3), 375–384 (1994).

Lee, J.K., Juh, D.J., Park, D., and Park, S., Sulfur dioxide adsorption over activated lignite char prepared from fluidized bed pyrolysis, Chem. Eng. Sci., 49(24A), 4483–4490 (1994).

Li, G.Q., Separation of oxygen from air using coordination complexes: A review, Ind. Eng. Chem. Res., 33(4), 755–783 (1994).

Li, J. and Talu, O., Adsorption equilibrium of benzene/para-xylene vapour mixture on silicalite, Chem. Eng. Sci., 49(2), 189–197 (1994). Isobaric isotherms (at 70°C and pressure levels of 2.53 and 1.20 kPa) are S-shaped, and selectivity curves at different pressures crossover; *p*-xylene selectivity at 2.53 kPa is higher than at 1.20 kPa over a certain composition range. This behavior is attributed to structural heterogeneity and is predicted by the heterogeneous ideal adsorbed solution model.

Mahle, J.J., Buettner, L.C., and Friday, D.K., Measurement and correlation of the adsorption equilibria of refrigerant vapors on activated carbon, Ind. Eng. Chem. Res., 33(2), 346–354 (1994). Comparison of various equations for the adsorption of four refrigerant vapors on BPL activated carbon at three temperatures over a wide range of partial pressures.

Mariwala, R.K. and Foley, H.C., Calculation of micropore sizes in carbogenic materials from the methyl chloride adsorption isotherm, Ind. Eng. Chem. Res., 33(10), 2314–2321 (1994).

Masthan, S.K., Rao, K.S.R., and Rao, P.K., The influence of metal loading on the structure-sensitive chemisorption of nitrogen on Ru/-alumina catalysts, Adsorpt. Sci. Technol., 11(3), 175–186 (1994).

Mentasty, L., Woestyn, A.M., and Zgrablich, G., High-pressure methane adsorption on natural and synthetic zeolites, Adsorpt. Sci. Technol., 11(2), 123–133 (1994). Adsorption isotherms obtained at various temperatures over the pressure range 0–5 MPa. Isotherms analyzed using the statistical thermodynamic adsorption model, and calculation of isosteric heat of adsorption. These zeolites are highly efficient for methane storage at moderately low pressure (0.5–1 MPa).

Moller, K.P., Kojima, M., and O'Connor, C.T., Diffusion and adsorption in zeolite Y and mordenite deactivated by propene oligomerization and hexane cracking, Chem. Eng. J., 54(3), 115–124 (1994). Effect of coke formation on diffusion and adsorption of propane, n-butane and isobutane in the pores of zeolite Y and mordenite.

Niwa, M., Yamazaki, K., and Murakami, Y., Separation of lower olefins by chemical vapor deposited zeolite-A, Ind. Eng. Chem. Res., 33(2), 371–374 (1994). Zeolite A was modified by CVD of silicon alkoxide which suppressed the rate of adsorption of lower olefins although the equilibrium adsorption amount was unchanged.

Pan, Z.J., Chen, S.G., Tang, J., and Yang, R.T., Pore structure alteration of a carbon molecular sieve for the separation of hydrogen sulfide from methane by adsorption, Adsorpt. Sci. Technol., 10, 193–202 (1994). Changing the pore structure by either controlled oxidation or carbon deposition by pyrolysis to enhance the overall selectivity (equilibrium plus kinetic) of hydrogen sulfide over methane. Useful for natural gas desulfurization by adsorption.

Payne, G.F., Patel, A.R., and Sun, W.Q., Tyrosinase reaction/chitosan adsorption: Potential for removing polymerization storage inhibitors, Ind. Eng. Chem. Res., 33(9), 2168–2173 (1994).

Pehlivan, E., Ersoz, M., Yildiz, S., and Duncan, H.J., Sorption of heavy metal ions on new metal-ligand complexes chemically derived from Lycopodium clavatum, Sep. Sci. Technol., 29(13), 1757–1768 (1994).

Polyakov, N.S., Larin, A.V., and Goubkina, M.L., Elution adsorption dynamics of organic substances on carbon adsorbents, Adsorpt. Sci. Technol., 10, 173–180 (1994). Experimental determination of breakthrough curves of CF_3Cl on carbon black and of cyclohexane on active charcoal.

Salas-Peregrin, M.A., Carrasco-Marin, F., Lopez-Garzon, F.J., and Moreno-Castilla, C., Adsorption of carbon dioxide on activated carbons from diluted ambient environments, Energy Fuels, 8(1), 239–243 (1994). Investigation of microporosity influence on adsorption capacity and adsorption kinetics. Experimental results show that the micropore size distribution is more important than either the micropore volume or the surface area alone. Activated carbons with a low degree of activation (greater number of narrow micropores) have a higher adsorption capacity than those with a higher micropore volume but with wider micropores. The diffusion parameter and the apparent activation energy of a process were also related to the size of micropores.

San, J.Y. and Jiang, G.D., Modeling and testing of a silica gel packed-bed system, Int. J. Heat Mass Transfer, 37(8), 1173–1179 (1994). Testing of a two-column packed-bed desiccant dehumidification system and regeneration stage. Modeling by a solid-side resistance method, including fluid friction effect which is shown to be significant for a long column or high inlet air velocity.

Sharma, D.C. and Forster, C.F., Compost as an adsorbent for the treatment of hexavalent chromium, Process Safety Environ. Prot., 72(B4), 234–240 (1994). Batch trials using coconut fibre compost showed that performance depended upon the pH (pH = 2 gave best results). Adsorption kinetics suggested that the process had a second-order reaction rate and that intraparticle diffusion together with the chemical binding reactions were the rate controlling steps.

Singh, B.K. and Rawat, N.S., Comparative sorption kinetic studies of phenolic compounds on fly ash and impregnated fly ash, J. Chem. Technol. Biotechnol., 61(1), 57–66 (1994). The process followed first-order rate kinetics, and intraparticle diffusion was found to be the rate-limiting step.

Singh, B.K. and Rawat, N.S., Comparative sorption equilibrium studies of toxic phenols on flyash and impregnated flyash, J. Chem. Technol. Biotechnol., 61(4), 307–318 (1994). The influences of particle size, impregnation of fly ash, pH and temperature on the sorption capacity were studied.

Smirniotis, P.G. and Ruckenstein, E., Comparison of the performance of ZSM-5, beta-zeolite-Y, USY, and their composites in the catalytic cracking of n-octane, 2,2,4-trimethylpentane, and 1-octene, Ind. Eng. Chem. Res., 33(4), 800–813 (1994).

Sorrento, L., The proven process of carbon adsorption, Chem. Eng. (N.Y.), July, 94–95 (1994). See Section 1.3.

Sun, W. and Costa, C.A.V., Activated diffusion of permanent gases in 4A zeolite at low coverage, Chem. Eng. Sci., 49(12), 1913–1923 (1994). A predictive methodology was developed for calculating intracrystalline diffusivities and diffusion activation energies of small molecular gases (argon, nitrogen, oxygen) in 4A zeolite. Good agreement with published experimental data.

Tsai, W.T. and Chang, C.Y., Adsorption of methylene chloride vapor on activated carbons, J. Chem. Technol. Biotechnol., 61(2), 145–151 (1994). Comparison of two activated carbons, BPL from bituminous coal and PCB from coconut shell at four temperatures between 283 and 313 K. The adsorption capacity of PCB was slightly higher than BPL, three adsorption equations were tested against the data and found to give satisfactory agreement.

Tung, L.A. and King, C.J., Sorption and extraction of lactic and succinic acids at pH > pKa1: Factors governing equilibria, and regeneration and process conditions, Ind. Eng. Chem. Res., 33(12), 3217–3229 (1994).

Wang, K., Hawley, M.C., and Reath, M.L., Adsorption model of HF on wood chips in a packed-bed reactor, Chem. Eng. Sci., 49(14), 2321–2329 (1994). Two adsorption rate limiting mechanisms exist for this process, namely HF supply control rate in the initial period (linear loading profile) followed by intrinsic adsorption control (non-linear profile). A mathematical model was developed to predict this behavior.

Yan, T.Y., A novel process for Hg removal from gases, Ind. Eng. Chem. Res., 33(12), 3010–3014 (1994).

Yoshida, H., Kishimoto, N., and Kataoka, T., Adsorption of strong acid on polyaminated highly porous chitosan: Equilibria, Ind. Eng. Chem. Res., 33(4), 854–859 (1994).

You, Y.H., Chiang, H.L., and Chiang, P.C., Comparison of adsorption characteristics for VOCs on activated carbon and oxidized activated carbon, Environ. Prog., 13(1), 31–36 (1994). Comparison of adsorption performance for an activated carbon with an oxidized sample which has been treated with NaOH solution or gas fluid with ozone.

1.3. Adsorbents

Anon., Reduce the risk of adsorbent bed fires during vapor recovery, Chem. Eng. (N.Y.), December, 127 (1994). Replacing high surface-area activated carbon with a new synthetic carbonaceous adsorbent called Ambersorb for removal of VOCs.

Arriagada, R., Garcia, R., and Reyes, P., Steam and carbon dioxide activation of Eucalyptus globulus charcoal, J. Chem. Technol. Biotechnol., 60(4), 427–435 (1994). Study of partial gasification of the charcoal using carbon dioxide and steam as activating agents. Both agents produce microporous ACs, and a large increase in meso- and macroporosity occurs with steam and high burn-off.

Balci, S., Dogu, T., and Yucel, H., Characterization of activated carbon produced from almond shell and hazelnut shell, J. Chem. Technol. Biotechnol., 60(4), 419–426 (1994). Ammonium chloride-impregnated and untreated samples were carbonized in nitrogen at relatively low temperatures. Treated adsorbents exhibited increased total surface area and improved sorption characteristics.

Bardina, I.A., Kalashnikova, E.V., Kovaleva, N.V., Rudnitskaya, T.A., and Shonya, N.K., Adsorption properties and structure of some active carbons, Adsorpt. Sci. Technol., 10, 211–220 (1994). Determination of low-coverage heats of adsorption of C_2–C_6 hydrocarbons on active carbon and graphitized carbon black (adsorbents classified as type I), and the porous structure of active carbon determined.

Barton, S.S., Evans, M.J.B., and MacDonald, J.A.F., Oxidized BPL carbons, Adsorpt. Sci. Technol., 10, 75-84 (1994). A series of oxidized carbons prepared by treatment with concentrated nitric acid at various temperatures, and surface and adsorption properties studied. The concentration of primary sites was seen to increase with increasing oxidation temperature.

Basta, N., New sorbents and adsorption processes, Chem. Eng. (N.Y.), November, 39–43 (1994). Improvements in adsorbents (mainly for environmental applications) by new surface treatment techniques and classification methods that allow precise control of particle and pore size distribution. Also improvements in PSA process performance.

Bhatia, S., Ghosh, B., and Agrawal, D.C., Synthesis of zeolite-A from calcined diatomaceous clay: Optimization studies, Ind. Eng. Chem. Res., 33(9), 2107–2110 (1994).

Botha, F.D. and McEnaney, B., Chemical activation of a South African coal using phosphoric acid, Adsorpt. Sci. Technol., 10, 181–192 (1994). Assessment of a South African coal as a precursor for a phosphoric acid-activated carbon, it produced a predominantly microporous adsorbent.

Chanda, M. and Rempel, G.L., Quaternized poly(4-vinylpyridine) gel-coated on silica: Fast kinetics of diffusion-controlled sorption of organic sulfonates, Ind. Eng. Chem. Res., 33(3), 623–630 (1994). A new anionic sorbent prepared as a thin layer on high surface-area silica by gel coating. Exhibits nearly 80% attainment of theoretical capacity and very much faster kinetics with 1-2 orders of magnitude higher rate of sorption and elution, compared to conventional resins, for removal of 2-naphthalenesulfonate from dilute aqueous solutions.

Cheng, L.S. and Yang, R.T., Improved Horvath-Kawazoe equations including spherical pore models for calculating micropore size distribution, Chem. Eng. Sci., 49(16), 2599–2609 (1994). Improvements in the H-K equations by introducing isotherm nonlinearity, and extending to spherical pores which is particularly useful for zeolites with cavities.

Davis, M.E., Zeolites: Can they be synthesized by design? Chemtech, 24(9), 22–26 (1994). Engineering a zeolite architecture by designed synthesis may be possible in the future by using spherosiloxanes as molecular building blocks.

Dubinin, M.M., Polyakov, N.S., and Petukhova, G.A., Porous structure and surface chemistry of active carbons, Adsorpt. Sci. Technol., 10, 17–26 (1994). Investigated the adsorbability of vapours with different physicochemical properties and a comparative analysis of the pore structure parameters; also the influence of the surface chemistry on the adsorption of water vapour.

Eligwe, C.A. and Okolue, N.B., Adsorption of iron(II) by a Nigerian brown coal, Fuel, 73(4), 569–572 (1994). Kinetics and mechanism of iron(II) adsorption from various solution conditions. The adsorption process is chemical, exhibits Langmuir behavior, and the initial rate is first-order with respect to solution concentration.

Girgis, B.S., Khalil, L.B., and Tawfik, T.A.M., Activated carbon from sugar cane bagasse by carbonization in the presence of inorganic acids, J. Chem. Technol. Biotechnol., 61(1), 87–92 (1994). Low-temperature carbonization produced an essentially microporous adsorbent with a low degree of mesoporosity. Higher temperatures produced higher surface area and total pore volume, with developed mesoporosity and low microporosity.

Goldstein, T.P. and Schmitt, K.D., Carbon centre types as determined by MAS-CP nmr on frozen fossil fuels, Fuel, 73(3), 397–403 (1994). Analysis of carbon centre types in fossil fuels, their fractions and reaction products, by spectroscopy.

Gomez-Serrano, V., Acedo-Ramos, M., Lopez-Peinado, A.J., and Valenzuela-Calahorro, C., Oxidation of activated carbon by hydrogen peroxide: Study of surface functional groups by FT-i.r., Fuel, 73(3), 387–396 (1994). Oxidation of outgassed activated carbon by H_2O_2 aqueous solutions. Investigated the influence of solution concentration and pH, outgassing and oxidation conditions of the carbon, and the addition of catalytic or stabilizer agents to the oxidizing solution. Significant changes in the surface chemistry of the samples were observed after a long period of time.

Goworek, J., Stefaniak, W., and Swiatkowski, A., The porosity of carbon materials as estimated by thermogravimetric analysis, Adsorpt. Sci. Technol., 11(2), 105–112 (1994). Determined the pore size distributions and total pore volumes of active carbons, and compared to adsorption/desorption isotherms for nitrogen and benzene vapour.

Guijarro, M.I., Mendioroz, S., and Munoz, V., Impact of the preparation conditions in the sulfur distribution of a new sulfurized porous adsorbent, Ind. Eng. Chem. Res., 33(2), 375–381 (1994). Fibrous natural silicates (sepiolite) were sulfurized (by Claus reaction) to be used for removal of mercury vapors. Studied effects of the operating conditions on the yield of sulfur deposited.

Gusler, G.M. and Cohen, Y., Equilibrium swelling of highly cross-linked polymeric resins, Ind. Eng. Chem. Res., 33(10), 2345–2357 (1994).

Haggin, J., Carbogenic sieves improve catalyst action, Chem. Eng. News, 19 December, 36–37 (1994).

Haggin, J., Molecular sieve with unique structural features synthesized, Chem. Eng. News, 4 July, 23 (1994). A new Mobil molecular sieve (MCM-22) having two independent pore systems, each accessible through a so-called 10-ring aperture.

Haupt, R.A. and Sellers, T., Characterizations of phenol-formaldehyde resol resins, Ind. Eng. Chem. Res., 33(3), 693–697 (1994). Preparation of various resol (plywood type) resins and effect of a wide range of variables.

Izumi, Y. and Iwasawa, Y., CO-breathing ruthenium and rhodium clusters, Chemtech, 24(7), 20–27 (1994). These supported catalysts have the unusual property of high CO uptake and, therefore, high activity in synthesis gas reactions.

Kabay, N., Preparation of amidoxime-fiber adsorbents based on poly(methacrylonitrile) for recovery of uranium from seawater, Sep. Sci. Technol., 29(3), 375–384 (1994). The prepared amidoxime-fiber adsorbent exhibited a large adsorption rate (e.g. 176 g-U/g-adsorbent/day) in a batchwise seawater adsorption test.

Khalil, L.B., Mourad, W.E., and Girgis, B.S., Changes in the surface area of silica-supported 12-molybdophosphoric acid in relation to the degree of loading and the calcination temperature, Adsorpt. Sci. Technol., 11(2), 83–94 (1994). The impregnated silicas showed considerable decrease in surface area as a function of their heteropoly acid content. Correlation with catalytic conversion of isopropanol indicated that activity was independent of surface area.

Kocjan, R. and Garbacka, M., Silica gel modified with methylthymol blue for separation and preconcentration of trace amounts of heavy metals from some salts, Sep. Sci. Technol., 29(6), 799–807 (1994). Sorption behavior depends upon the species and pH of the loading solution; alkali-metal ions were not retained. Retained metals can be eluted with dilute acids.

Ku, B.J., Lee, J.K., and Rhee, H.K., Treatment of activated carbon to enhance catalytic activity for reduction of nitric oxide with ammonia, Ind. Eng. Chem. Res., 33(11), 2868-2874 (1994).

Kumar, M. and Gupta, R.C., Correlation of reactivity and properties of wood chars, Fuel, 73(11), 1805–1806 (1994). Correlations between reactivity and electrical, structural and physical properties (easier to measure for quality control) of acacia and eucalyptus wood chars.

Leboda, R., Grzegorczyk, W., Lodyga, A., and Dabrowski, A., Effect of catalytic gasification of active carbon from plum stones on its mesoporous structure, Adsorpt. Sci. Technol., 10, 221–240 (1994). Determination of the characteristics of the micro- and meso-porous structures of the adsorbents after gasification with water vapour with (and without) calcium(II) catalyst.

Liu, H. and Seaton, N.A., Determination of the connectivity of porous solids from nitrogen sorption measurements. III. Solids containing large mesopores, Chem. Eng. Sci., 49(11), 1869–1878 (1994). Modification of a method for determination of the connectivity of porous solids for large mesopores which allows narrow bounds on the mean coordination number of the pore network to be calculated.

Lu, G.Q. and Do, D.D., Development of carbonaceous adsorbents from coal reject for acidic gases removal, Gas Sep. Purif., 8(1), 17–30 (1994). Kinetics of coal-rejects pyrolysis and the structural changes as well as activation were studied by experiment and modeling. Shown to be useful adsorbents for SO*x*/NO*x* removal.

Mariwala, R.K. and Foley, H.C., Evolution of ultramicroporous adsorptive structure in poly(furfuryl alcohol)-derived carbogenic molecular sieves, Ind. Eng. Chem. Res., 33(3), 607–615 (1994). Production of adsorbents and influence of synthesis temperature (from 400–1200°C) and soak time (0–8 hours).

Milewska-Duda, J., Ceglarska-Stefanska, G., and Duda, J., A comparison of theoretical and empirical expansion of coals in the high pressure sorption of methane, Fuel, 73(6), 975–979 (1994). Sorption and expansion measurements were carried out on coals with different degrees of metamorphism at 298 K and pressure range 0.5–4.5 MPa. Very good agreement was observed between theoretical and experimental values in the lower pressure range. Differences observed in the higher pressure range suggest significant pore compression.

Pan, Z.J., Chen, S.G., Tang, J., and Yang, R.T., Pore structure alteration of a carbon molecular sieve for the separation of hydrogen sulfide from methane by adsorption, Adsorpt. Sci. Technol., 10, 193–202 (1994).

Park, T.G. and Hoffman, A.S., Estimation of temperature-dependent pore size in poly(N-isopropylacrylamide) hydrogel beads, Biotechnol. Prog., 10(1), 82–86 (1994). Use of a gel filtration method showed that pore sizes are affected significantly by the temperature and the gel composition, but not much by cross-linker concentration.

Petrov, N., Gergova, K., and Eser, S., Effect of water vapour on the porous structure of activated carbon from lignite, Fuel, 73(7), 1197–1201 (1994). Activated carbon produced from a Bulgarian lignite by steam pyrolysis at 650°C has a more developed porous structure, higher surface area, and increased adsorption capacity for iodine and methylene blue (compared to AC produced by pyrolysis in argon atmosphere).

Pielaszek, J., X-ray powder diffractometry in studies of solid carbons, Fuel, 73(11), 1792–1796 (1994). Comparison of microcrystalline structure of solid carbons as determined by wide-angle X-ray diffraction pattern and from analysis of radial distribution function curves.

Polyakov, N.S., Petukhova, G.A., Vnukov, S.P., and Shevchenko, A.O., The hydrophobization of active carbons, Adsorpt. Sci. Technol., 10, 165–172 (1994). Three methods investigated: (i) chemical modification; (ii) heat treatment with uhf electromagnetic field; (iii) heat treatment with low-frequency electromagnetic field. Methods involving physical modification are preferable with decreased water adsorbability.

Razvigorova, M., Goranova, M., Minkova, V., and Cerny, J., On the composition of volatiles evolved during the production of carbon adsorbents from vegetable wastes, Fuel, 73(11), 1718–1722 (1994). Analysis of the gas and liquid products evolved during steam pyrolysis of apricot stones and coconut shells.

Rudzinski, W., Nieszporek, K., and Dabrowski, A., Application of the Dubinin-Astakhov equation to the study of the geometric structure, energetic surface heterogeneity and surface topography of carbonaceous adsorbents, Adsorpt. Sci. Technol., 10, 35–62 (1994). Theoretical approach to multisite-occupancy adsorption on heterogeneous surfaces, and adsorption energy distribution.

Ruplis, A. and Bumans, R., The influence of acid treatment on the sorption properties of Latvian clays, Adsorpt. Sci. Technol., 10, 137–146 (1994). Sorption of n-hexane and carbon tetrachloride vapours on two series of Latvian clays (at 20°C).

Segarra, E.I. and Glandt, E.D., Model microporous carbons: Microstructure, surface polarity and gas adsorption, Chem. Eng. Sci., 49(17), 2953–2965 (1994). A new molecular model for activated carbons consisting of a collection of randomly oriented carbon crystallites.

Sengupta, A.K. and Zhu, Y., Selective and reversible ligands sorption through a novel regeneration scheme, Ind. Eng. Chem. Res., 33(2), 382–386 (1994). A new class of tailored chelating polymers show high sorption affinity toward anionic ligands of environmental importance, namely oxalate, phthalate, selenite, and arsenate. Presents a new two-bed regeneration scheme with high desorption efficiency, which means ligand recovery from dilute solutions may now be possible.

Sharma, D.C. and Forster, C.F., Compost as an adsorbent for the treatment of hexavalent chromium, Process Safety Environ. Prot., 72(B4), 234–240 (1994). See Section 1.2.

Siriwardane, R.V., Poston, J.A., and Evans, G., Spectroscopic characterization of molybdenum-containing zinc titanate desulfurization sorbent, Ind. Eng. Chem. Res., 33(11), 2810–2818 (1994).

Sorrento, L., The proven process of carbon adsorption, Chem. Eng. (N.Y.), July, 94–95 (1994). Filtration with activated carbon as a cost-effective method of process water treatment for removal of VOCs, soluble organic compounds and other adsorbable materials.

Stoeckli, F. and Huguenin, D., Pretreatment and physical activation of acetylene cokes, Fuel, 73(12), 1929–1930 (1994). Preteatment at 450°C with a mixture of nitrogen, oxygen and water vapour creates a relatively large surface area and some initial microporosity, further developed by water activation at 800°C.

Tarasevich, Y.I., Zhukova, A.I., Aksenenko, E.V., Bondarenko, S.V., and Nazarenko, O.V., Study of the structure of a surface-porous adsorbent using the gas chromatographic version of the molecular probe method, Adsorpt. Sci. Technol., 10, 147–154 (1994). This method can reliably estimate the size of the surface micropores of a silica-based surface-porous adsorbent.

Xu, Y., Koga, Y., and Watkinson, A.P., Pore size distribution of coals and chars from Western Canada, Fuel, 73(11), 1797–1801 (1994). Highly reactive chars from low-rank coals showed increased total pore volumes after pyrolysis, whereas the total pore volumes decreased for poorly reactive chars from high-rank coals.

1.4. PSA and Cyclic Systems, and Applications

Alpay, E., Kenney, C.N. and Scott, D.M., Adsorbent particle size effects in the separation of air by rapid pressure swing adsorption, Chem. Eng. Sci., 49(18), 3059–3075 (1994). An optimum particle size for maximum cyclic equilibrium product oxygen purity is shown to exist and can be predicted by model simulation. Poor separation occurs in beds containing very small particles due to ineffective pressure swing, and with very large particles due to intraparticle diffusional limitations.

Basta, N., New sorbents and adsorption processes, Chem. Eng. (N.Y.), November, 39–43 (1994). See Section 1.3.

Chiang, A.S.T., Chung, Y.L., Cheng, C.-W., Hung, T.-H., and Lee, T.Y., Experimental study on a four-bed PSA air separation process, AIChE J., 40(12), 1976–1982 (1994). A 200 sec cycle with both pressure equalization and product backfill steps, operated under a pressure ratio of 4.3. System can produce over 90% oxygen at a recovery of 17%.

Chou, C.-T. and Huang, W.-C., Incorporation of a valve equation into the simulation of a pressure swing adsorption process, Chem. Eng. Sci., 49(1), 75–84 (1994). The valve equation for flow rates at both ends of a bed, with transient flows, is incorporated into the simulations of carbon molecular sieve-air and 5A zeolite-air systems.

Chou, C.-T. and Huang, W.-C., Simulation of a four-bed pressure swing adsorption process for oxygen enrichment, Ind. Eng. Chem. Res., 33(5), 1250–1258 (1994).

Chou, C.-T., Wu, C.-L., and Chiang, A.S.T., A complementary pressure swing adsorption process configuration for air separation, Sep. Technol., 4(2), 93–103 (1994). Use of two adsorbents to produce both enriched oxygen up to 99.57% (at 34.44% recovery) and enriched nitrogen at 98% (47.86% recovery) from a four-bed air separation process.

Crittenden, B.D., Guan, J., Ng, W.N., and Thomas, W.J., Dynamics of pressurization and depressurization during pressure swing adsorption, Chem. Eng. Sci., 49(16), 2657–2669 (1994). Comparison of times for pressurization and depressurization of a bed of either non-adsorbent or adsorbent particles, and comparison of two models with experimental data.

Farooq, S., Rathor, M.N., and Hidajat, K., A modified continuous countercurrent flow model for a PSA separation process, Chem. Eng. Res. Des., 72(1), 114–118 (1994). Extending a model with pressurization-blowdown steps and adsorption-purge steps having equal duration, to cycles where the times of these individual steps are different.

Kirkby, N.F. and Morgan, J.E.P., A theoretical investigation of pressure swing reaction, Chem. Eng. Res. Des., 72(4), 541–550 (1994). A mathematical model for PSR has been formulated and solved numerically

by the method of characteristics. Results of simple cycles at low product amounts show a separation inversion compared to conventional PSA. In comparison with simple plug flow and fully mixed reactors, a PSR offers process intensification by the combination of reaction with primary product separation.

Kovvali, S.A., Vemury, S., and Admassu, W., Modeling of multicomponent countercurrent gas permeators, Ind. Eng. Chem. Res., 33(4), 896–903 (1994).

Kumar, R., Pressure swing adsorption process: Performance optimum and adsorbent selection, Ind. Eng. Chem. Res., 33(6), 1600–1605 (1994).

Kumar, R., Fox, V.G., Hartzog, D.G., Larson, R.E., Chen, Y.C., Houghton, P.A., and Naheiri, T., A versatile process simulator for adsorptive separations, Chem. Eng. Sci., 49(18), 3115–3125 (1994). Development of a new nonisothermal, nonlinear, nonequilibrium and nonisobaric model to accurately simulate an adsorption-separation process. Validated by comparison with experimental data for PSA processes.

Lu, Z.P. and Rodrigues, A.E., Pressure swing adsorption reactors: Simulation of three-step one-bed process, AIChE J., 40(7), 1118–1137 (1994). An equilibrium model was derived to describe a three-step (feed, delay, purge), one-column PSA reactor. Comparison was made with the reversible dehydrogenation reaction of ethane to ethylene and hydrogen on Cd-exchanged zeolites, where one or both products were adsorbed.

Naumov, V.A., Vorotynthev, V.B., and Kusiy, G.V., Non-isothermal regeneration of molecular sieve adsorbers in a cyclic process of air purification from moisture and carbon dioxide, Gas Sep. Purif., 8(3), 167–174 (1994). A model predicts that carbon dioxide desorption temperature should be below 353 K, whereas minimum moisture desorption temperature should be within the range 373–423 K. Calculations were compared to test data from a low-pressure air separation plant.

Oliveira, F., de Oliviera, P., Ceu Lopes, M., and Castro, J.A.A.M., Two adaptive grid methods for fixed bed systems simulation, Comput. Chem. Eng., 18(3), 227–243 (1994). Comparison of two adaptive gridding algorithms, based on the Method of Lines, are proposed for the numerical solution of the PDE which describes the energy balance of a fixed bed system.

Rajniak, P. and Yang, R.T., Hysteresis-dependent adsorption-desorption cycles: Generalization for isothermal conditions, AIChE J., 40(6), 913–924 (1994). Various and distinct types of equilibrium cycles are observed (for the water vapor-silica gel system at 25°C) depending on the relative positions of the limiting partial pressures with respect to the closure points of the main hysteresis loop as well as the history of the cycle.

Reiss, G., Status and development of oxygen generation process on molecular sieve zeolites, Gas Sep. Purif., 8(2), 95–100 (1994). PSA processes are reliable and have long service life. The main methods are PSA, vacuum swing adsorption (VSA), and pressure vacuum swing adsorption (PVSA). Two new variations are low-temperature VSA and two-bed VSA. Capacity limits are restricted by the design of the valves and vacuum pumps.

Reunanen, J., Palosaari, S., Miyahara, M., and Okazaki, M., Reliable numerical calculation of the breakthrough curve of an adsorption column, Chem. Eng. Process., 33(3), 117–123 (1994). Development of a numerical method and simplification to reduce the computation time required.

Ruthven, D.M. and Farooq, S., Concentration of a trace component by pressure swing adsorption, Chem. Eng. Sci., 49(1), 51–60 (1994). For high selectivity, the lighter component is desorbed first during blowdown and then the more strongly adsorbed species recovered by vacuum desorption. Compared to a cryogenic PSA process for recovery of hydrogen from a helium carrier.

Ruthven, D.M. and Inui, T., Letter and reply concerning "Carbon dioxide/nitrogen separation by PSA using metal-incorporated crystals," Gas Sep. Purif., 8(1), 53 (1994). Consideration of use of unstable H-form of zeolite-A and replacement by Na-A adsorbent.

Salasivam, M. and Balakrishnan, A.R., Experimental investigations on the thermal effects in packed bed liquid desiccant dehumidifiers, Ind. Eng. Chem. Res., 33(6), 1636–1640 (1994).

Scott, D.M., The linear driving force model for cyclic adsorption and desorption: The effect of shape, Chem. Eng. Sci., 49(6), 914–916 (1994). Effect of non-spherical particle shape on the linear driving force approximation model used for the calculation of adsorptive diffusional resistances.

Shamsur Rahman, A.K.M., Hassan, M.M., and Loughlin, K.F., Unsteady state simulation of "SORBEX" system with nonlinear adsorption isotherms, Sep. Technol., 4(1), 27–37 (1994). Study showed that system performance and dynamics are strongly dependent on bed length, column diameter, feed and eluent flow rate, switch time, and nonlinearity of the isotherm, and there exists a set of optimum values for best performance. Good agreement between the model simulation and experimental results for glucose-fructose (linear isotherms) and monoethanolamine-methanol (nonlinear isotherms).

Shirley, A.I. and Kikkinides, E.S., Comments and reply on "Concentration and recovery of carbon dioxide from flue gas by pressure swing adsorption," Ind. Eng. Chem. Res., 33(11), 2879–2881 (1994).

Tsuru, T. and Hwang, S.T., Production of high-purity oxygen by continuous membrane column combined with PSA oxygen generator, Ind. Eng. Chem. Res., 33(2), 311–316 (1994).

1.5. Liquid-Phase Adsorption

Abbasi, W.A. and Streat, M., Adsorption of uranium from aqueous solutions using activated carbon, Sep. Sci. Technol., 29(9), 1217–1230 (1994). Treatment with hot nitric acid oxidized the surface of the activated carbon and significantly increased the adsorption capacity for uranium in near-neutral and slightly acidic nitrate solutions.

Bohra, P.M., Vaze, A.S., Pangarkar, V.G., and Taskar, A., Adsorptive recovery of water soluble essential oil components, J. Chem. Technol. Biotechnol., 60(1), 97–102 (1994). Steam distillation of many essential oils results in the preferential loss of valuable oxygenated components (having higher solubility) in the distillate water. Examines the use of synthetic polymeric adsorbents to recover these organics (phenyl ethyl alcohol, linalool and eugenol).

Brewster, M.D. and Passmore, R.J., Use of electrochemical iron generation for removing heavy metals from contaminated groundwater, Environ. Prog., 13(2), 143–148 (1994). Possible use of activated carbon in groundwater cleanup using electrochemical techniques.

Budinova, T.K., Gergova, K.M., Petrov, N.V., and Minkova, V.N., Removal of metal ions from aqueous solution by activated carbons obtained from different raw materials, J. Chem. Technol. Biotechnol., 60(2), 177–182 (1994). Influence of solution pH on adsorption of Pb, Cu, Zn and Cd ions (at 293 K) by activated carbons prepared from apricot stones, coconut shells and lignite coal. The presence of other metal ions in solution decreases the adsorption of each of the ions, selective adsorption is observed but the ones preferentially adsorbed do not completely prevent the adsorption of other ions. The chemical nature of the carbon surface and metal ions have great significance for the adsorption process.

Chatzopoulos, D., Varma, A., and Irvine, R.L., Adsorption and desorption studies in the aqueous phase for the toluene/activated carbon system, Environ. Prog., 13(1), 21–25 (1994). Experimental data and model comparison for toluene in single-component aqueous solutions.

Cooney, D.O. and Xi, Z., Activated carbon catalyzes reactions of phenolics during liquid-phase adsorption, AIChE J., 40(2), 361–364 (1994). Batch adsorption studies of powdered activated carbon for removal of various phenolic compounds in aqueous buffer solutions showed slow (several weeks) but continual adsorption.

Dabrowski, A., Nieszporek, K., Fekner, Z., Leboda, R., and Garbacz, J.K., Application of the Dubinin-Radushkevich equation for describing adsorption from solutions on to various carbons, Adsorpt. Sci. Technol., 10, 105–122 (1994). Description of adsorption from binary solutions of non-electrolytes onto both homogeneous and heterogeneous surfaces from ideal and non-ideal liquid mixtures. Important parameters include the surface heterogeneity, interactions between the species in the bulk and surface phases, and differences in molecular sizes of the adsorbate molecules.

Egawa, H., Kabay, N., Jyo, A., Hirono, M., and Shuto, T., Recovery of uranium from seawater. 15. Development of amidoxime resins with high sedimentation velocity for passively driver fluidized bed adsorbers, Ind. Eng. Chem. Res., 33(3), 657–661 (1994). Development of suitable amoxidime resins for uranium recovery from seawater in a circulating fluidized bed. Various properties were measured and evaluated.

Ellis, J. and Korth, J., Removal of nitrogen compounds from hydrotreated shale oil by adsorption on zeolite, Fuel, 73(10), 1569–1573 (1994). US-Y zeolite used to adsorb eight aromatic nitrogen compounds, which could be regenerated by combustion. Zeolite adsorption is an alternative to severe hydrotreatment.

Eltekova, N.A. and Eltekov, Y.A., Application of the DR and DS equations to benzene adsorption from water solutions, Adsorpt. Sci. Technol., 10, 203–210 (1994). Application of the theory of micropore filling to this system, results suggesting that the activated carbons used are characterized by heterogeneous microporosity.

Ghosh, D.R. and Keinath, T.M., Effect of clay minerals present in aquifer soils on the adsorption and desorption of hydrophobic organic compounds, Environ. Prog., 13(1), 51–59 (1994). Studies indicated that expandable clay minerals had a significant impact on naphthalene (used as a test surrogate contaminant) partitioning.

Ghosh, M.M., Cox, C.D., and Yuan-Pan, J., Adsorption of selenium on hydrous alumina, Environ. Prog., 13(2), 79–88 (1994). Batch equilibrium experiments on adsorption of selenite and selenate. The most significant parameter was pH affecting both speciations and of surface hydroxo groups on alumina, and therefore the extent of adsorption of the oxyanions. Spent alumina beds could be regenerated.

Gonzalez-Martin, M.L., Janczuk, B., Bruque, J.M., and Dorado-Calasanz, C., Adsorption of sodium dodecyl sulphate on cassiterite surface, Can. J. Chem. Eng., 72(3), 551–554 (1994). Adsorption depended on the manner of preparation of the cassiterite and the solution pH.

Gonzalez Pradas, E., Villafranca Sanchez, M., Canton Cruz, F., Socias Viviana, M., and Fernandez Perez, M., Adsorption of cadmium and zinc from aqueous solution on natural and activated bentonite, J. Chem. Technol. Biotechnol., 59(3), 289–295 (1994). Natural bentonite was heat treated at 110°C or 200°C, or activated by acid treatment with H_2SO_4 from aqueous solution at 30°C. Adsorption isotherms for Cd and Zn may be classified respectively as H and L types of the Giles classification, suggesting that the samples have respectively a high and a medium affinity for Cd and Zn ions.

Gonzalez Pradas, E., Villafranca Sanchez, M., Socias Viviana, M., and Gallegoi Campo, A., Adsorption of chlorophyll-a from acetone solution on natural and activated bentonite, J. Chem. Technol. Biotechnol., 61(2), 175–178 (1994). Natural bentonite and various treated activated samples were obtained and tested, the isotherms being classified (Giles) as types S (untreated), H and L indicating low, high and medium affinity, respectively.

Goubkina, M.L., Polyakov, N.S., and Tatarinova, L.I., Immersion heats of active carbons in water and organic substances, Adsorpt. Sci. Technol., 10, 27–34 (1994). Changes in the immersion heats correspond to pore structure characteristics such as micropores size distribution.

Harmon, T.C. and Roberts, P.V., The effect of equilibration time on desorption rate measurements with chlorinated alkenes and aquifer particles, Environ. Prog., 13(1), 1–8 (1994). Testing of two types of aquifer solids for removal of chlorinated alkenes.

Hassan, N.M., The adsorption of long-chain *n*-paraffin from isooctane solution on crystalline urea, Sep. Technol., 4(1), 62–64 (1994). Extension of previous work on adsorption of small- and medium-chains to long-chain n-paraffins.

Hassan, N.M., Al-Ameeri, R.S., and Oweysi, F.A., Adsorption of n-paraffin wax from isooctane solution on crystalline urea, Sep. Sci. Technol., 29(7), 897–906 (1994). Equilibrium isotherms and kinetic data were measured, and suggest that the adsorption is diffusion controlled.

Ho, Y.S., Wase, D.A.J., and Forster, C.F., The adsorption of divalent copper ions from aqueous solution by sphagnum moss peat, Process Safety Environ. Prot., 72(B3), 185–194 (1994). The process was found to be pH dependent, the optimum range being 4.0–5.0. Data compared to models developed, and the adsorption kinetics were also studied.

Hobday, M.D., Li, P.H.Y., Crewdson, D.M., and Bhargava, S.K., The use of low-rank coal-based adsorbents for the removal of nitrophenol from aqueous solution, Fuel, 73(12), 1848–1854 (1994). Investigated the influence of adsorbent dosage levels, particle size, pH, and the presence of buffer solution components and other electrolytes on adsorption kinetics.

Holtzapple, M.T. and Brown, R.F., Conceptual design for a process to recover volatile solutes from aqueous solutions using silicalite, Sep. Technol., 4(4), 213–229 (1994). Recovery and concentration (by desorption) of ethanol and butanol by adsorption on pure silicalite powder in the annular space between two concentric porous pipes. Steam passage through the heat exchanger enables regeneration and desorption.

Holtzapple, M.T., Flores, K.L., and Brown, R.F., Recovery of volatile solutes from dilute aqueous solutions using immobilized silicalite, Sep. Technol., 4(4), 230–238 (1994). A silicalite/polyethylene mixture was sintered to a heat exchanger tube (immobilised) so that it could be easily regenerated, and was used to adsorb ethanol, acetone and butanol from aqueous solutions and hence concentrate these solutes by desorption.

Jain, A.K. and Gupta, A.K., Adsorptive drying of isopropyl alcohol on 4A molecular sieves: Equilibrium

and kinetic studies, Sep. Sci. Technol., 29(11), 1461–1472 (1994). Batch equilibrium and kinetic studies of water adsorption from aqueous solution of isopropyl alcohol on 4A molecular sieves.

Kabay, N. and Egawa, H., Chelating polymers for recovery of uranium from seawater, Sep. Sci. Technol., 29(1), 135–150 (1994). Considers the use of chelating polymeric resins containing amidoxime groups as adsorbents for uranium from seawater.

Kabil, M.A. and Ghazy, S.E., Separation of some dyes from aqueous solutions by flotation, Sep. Sci. Technol., 29(18), 2533–2539 (1994).

Kataoka, T., Muto, A., and Nishiki, T., Adsorption equilibria of soluble silica into an OH-type strong anion exchange resin from a dilute solution, Chem. Eng. Res. Des., 72(6), 777–782 (1994). The adsorption behaviour was explained by both ion exchange and polymerization reactions of silica. The pH values of both solutions, and coexisting anion concentration, affected the equilibrium of silica into the resin. For effective separation, the pH value of the silica solution should be in the range 8–10.

Kesraoui-Ouki, S., Cheeseman, C.R., and Perry, R., Natural zeolite utilisation in pollution control: A review of applications to metal's effluents, J. Chem. Technol. Biotechnol., 59(2), 121–126 (1994). Assesses the potential of natural zeolites as a low-cost ion-exchange and sorbent materials for the treatment of heavy metal contaminated soil and water.

Kusakabe, K., Goto, A., and Morooka, S., Kinetics of uranium adsorption from seawater with imidedioxime adsorbent, Sep. Sci. Technol., 29(12), 1567–1577 (1994). Investigated the complexation between glutar-imidedioxime and uranyl ion in artificial seawater at pH 10.3 containing 600 ppm uranium.

Kusakabe, K., Isumi, N., and Morooka, S., Desorption of uranium recovered with fibrous amidoxime adsorbent shaped into balls, Sep. Sci. Technol., 29(11), 1501–1508 (1994). Amidoxime fiber synthesized with a commercial PAN fiber was packed in 2 cm diameter spherical shells made of plastic net. The adsorbent balls were then packed in a cage through which seawater was passed and uranium was adsorbed, and subsequently desorbed.

Leyva-Ramos, R. and Geankoplis, C.J., Diffusion in liquid-filled pores of activated carbon. I. Pore volume diffusion, Can. J. Chem. Eng., 72(2), 262–271 (1994). Adsorption isotherms measured for the following six systems: benzaldehyde, phenol, and potassium chloride in water; and benzene, isopropylbenzene, and phenol in cyclohexane.

Littel, R.J., Versteeg, G.F., and van Swaaij, W.P.M., Physical absorption of carbon dioxide and propene into toluene/water emulsions, AIChE J., 40(10), 1629–1638 (1994). The physical absorption was studied in a stirred cell and a laminar film absorber, and experimental mass transfer rates compared to predictions of an absorption model based on Higbie's penetration theory.

Mishra, S.P. and Chaudhury, G.R., Kinetics of zinc adsorption on charcoal, J. Chem. Technol. Biotechnol., 59(4), 359–364 (1994). Various parameters were studied and the kinetics followed a Freundlich isotherm, the rate determining step was diffusion controlled.

Nassar, M.M. and El-Geundi, M.S., Studies of the dimensionless mass-transfer coefficient during the adsorption of basic and acid dyes on to bagasse pith, Adsorpt. Sci. Technol., 11(2), 73–82 (1994). The influence of agitation, particle diameter and adsorbent mass on the external mass-transfer coefficient is discussed. The computed values correlate linearly with the dimensionless function [Sh/Sc$^{0.33}$].

Nirdosh, I., Vogl, A.K., and Carroll, S.M., Removal of 230Th and other metals from sulphuric acid leach uranium mill solution by solvent extraction, adsorption and precipitation, Dev. Chem. Eng. Mineral Process., 2(2), 171–180 (1994).

Olguin, M.T., Solache, M., Asomoza, M., Acosta, D., Bosch, P., and Bulbulian, S., UO_2^{2+} Sorption in natural Mexican erionite and Y-zeolite, Sep. Sci. Technol., 29(16), 2161–2178 (1994). Determined the effects of various parameters on the removal of uranyl ions from aqueous solutions. The diffusion coefficients are not clearly affected by temperature or concentration, but they definitely depend on the structure of each zeolite.

Parker, W.J., Bell, J.P., and Melcer, H., Modelling the fate of chlorinated phenols in wastewater treatment plants, Environ. Prog., 13(2), 98–104 (1994). Behavior of chlorinated phenols in activated sludge wastewater plants was investigated. Batch sorption studies and steady-state and dynamic continuous flow experiments were performed to determine partitioning between the liquid and solid phases, and biodegradation rate coefficients.

Pehlivan, E., Ersoz, M., Yildiz, S., and Duncan, H.J., Sorption of heavy metal ions on new metal-ligand complexes chemically derived from Lycopodium

clavatum, Sep. Sci. Technol., 29(13), 1757–1768 (1994). Sorption from aqueous solution as a function of pH using a novel exchanger system.

Peng, F.F. and Di, P., Removal of arsenic from aqueous solution by adsorbing colloid flotation, Ind. Eng. Chem. Res., 33(4), 922–928 (1994).

Periasamy, K. and Namasivayam, C., Process development for removal and recovery of cadmium from wastewater by a low-cost adsorbent: Adsorption rates and equilibrium studies, Ind. Eng. Chem. Res., 33(2), 317–320 (1994). Activated carbon prepared from peanut hulls was used for Cd(II) removal, and it was found to have an adsorption capacity thirty times greater than commercial granular activated carbon.

Pizzio, L.R., Cacares, C.V., and Blanco, M.N., Adsorption of tungsten and alumina from sodium tungstate solutions: Estimation of equilibrium and kinetic parameters, Adsorpt. Sci. Technol., 11(3), 133–144 (1994).

Rao, M.B. and Sircar, S., Liquid-phase adsorption of bulk ethanol-water mixtures by alumina, Adsorpt. Sci. Technol., 10, 93–104 (1994). Separation of the mixtures can be carried out by selective adsorption on Alcoa H152 alumina, with easier and less energy intensive desorption of the water.

Rauf, M.E., Hasany, S.M., Ikram, M., and Shamsi, A.M., Adsorption of europium onto titanium oxide from aqueous solutions, Adsorpt. Sci. Technol., 11(3), 187–191 (1994).

Rauf, M.A., Hasany, S.M., Iqbal, M.J., and Hussain, M.T., Adsorption studies of europium on manganese dioxide from aqueous sulphuric acid and 1-propanol mixtures, Adsorpt. Sci. Technol., 11(3), 155–160 (1994).

Reed, B.E., Arunachalam, S., and Thomas, B., Removal of lead and cadmium from aqueous waste streams using granular activated carbon (GC) columns, Environ. Prog., 13(1), 60–64 (1994). Wastewater containing acetic acid or EDTA, experiments showed that column pH is the critical parameter influencing column performance. The column could also be regenerated by nitric acid followed by NaOH.

Saleem, M., Afzal, A., Naeem, T.M., and Mahmood, F., Adsorption characteristics of organic dyes on alumina powder from aqueous solutions, Adsorpt. Sci. Technol., 11(2), 95–104 (1994). Adsorption investigated as a function of shaking time, amount of adsorbent, concentration of adsorbate and temperature. Isotherms are S-type and obey the Freundlich equation.

Salem, A.B.S.H., Naphtha desulfurization by adsorption, Ind. Eng. Chem. Res., 33(2), 336–340 (1994). Comparison and evaluation of activated carbon and zeolites for removal of sulfur compounds from naphtha solutions.

Scholl, S. and Mersmann, A., Binary adsorption on single adsorbent particles, Int. Chem. Eng., 34(3), 288–291 (1994). Binary adsorption equilibria and kinetics of water-tetrachloroethylene on single particles of active carbon was studied experimentally and compared to a pore diffusion model.

Sekiguchi, K., Saito, K., Konishi, S., Furusaki, S., Sugo, T., and Nobukawa, H., Effect of seawater temperature on uranium recovery from seawater using amidoxime adsorbents, Ind. Eng. Chem. Res., 33(3), 662–666 (1994). Results of uranium adsorption on porous amidoxime hollow fibres indicated that chelate formation of the amidoxime group with uranyl species was the rate-determining step.

Stang, M., Karbstein, H., and Schubert, H., Adsorption kinetics of emulsifiers at oil-water interfaces and their effect on the mechanical emulsification, Chem. Eng. Process., 33(5), 307–311 (1994). Adsorption kinetics of the emulsifiers dodecyl alcohol-10-glycol ether, a whey protein concentrate, and egg yolk were measured, and oil-water emulsions prepared and their effect on adsorption was investigated.

Taha, F., Saleh, M.B., Attyia, K.M.E., and Khalaf, M.M.R., Electrokinetic properties of cassiterite and quartz particles in the presence of cationic, anionic and non-ionogenic surfactants, Adsorpt. Sci. Technol., 11(3), 161–174 (1994).

Takatsuji, W. and Yoshida, H., Removal of organic acids from wine by adsorption on weakly basic ion exchangers: Equilibria for single and binary systems, Sep. Sci. Technol., 29(11), 1473–1490 (1994). Use of weakly basic resins made from chitosan, acryl, and styrene to selectively adsorb citric acid and malic acid from wine.

Taylor, R.M. and Kuennen, R.W., Removing lead in drinking water with activated carbon, Environ. Prog., 13(1), 65–71 (1994). Testing a fixed-bed adsorber for reduction of soluble and insoluble lead showed the importance of carbon surface chemistry and solution pH.

Theis, T.L., Iyer, R., and Ellis, S.K., Parameter estimation for trace element sorption on a new granular iron oxide, Environ. Prog., 13(1), 72–77 (1994).

Obtaining data for sorption of trace elements of cadmium and chromate on a granular form of iron oxide in a batch reactor and a packed column.

Yang, X., Tsai, G.J., and Tsao, G.T., Enhancement of in-situ adsorption on the acetone-butanol fermentation by Clostridium acetobutylicum, Sep. Technol., 4(2), 81–92 (1994). In-situ adsorption of toxic products using polyvinylpyridine enhanced the fermentation rates and the reactor productivity.

Yoshida, H., Nishihara, H., and Kataoka, T., Adsorption of BSA on DEAE-dextran: Equilibria, Sep. Sci. Technol., 29(17), 2227–2244 (1994). Equilibrium isotherms were not dependent on the BSA initial concentration but were considerably affected by pH. They were correlated by the Langmuir equation for $pH > 5.05$, and by the Freundlich equation at $pH = 4.8$. The amount of BSA adsorbed on univalent-form resin decreased when the liquid-phase equilibrium concentration of BSA was increased.

Young, D.F. and Ball, W.P., A-Priori simulation of tetrachloroethane transport through aquifer material using an intraparticle diffusion model, Environ. Prog., 13(1), 9–20 (1994). Investigated the breakthrough of tetrachloroethene in packed columns and comparison with a transport model.

Zouboulis, A.I., Lazaridis, N.K., and Zamboulis, D., Powdered activated carbon separation from water by foam flotation, Sep. Sci. Technol., 29(3), 385–400 (1994). Separation of adsorbent from dilute aqueous suspensions using anionic and cationic surfactants. Investigated the effects of surfactant type, suspension pH, initial carbon and surfactant concentrations, flotation time, and air flowrate on dispersed-air flotation.

1.6. Ion Exchange, Chromatography, etc.

Ahn, D.J. and Franses, E.I., Ion adsorption and ion exchange in ultrathin films of fatty acids, AIChE J., 40(6), 1046–1054 (1994). Experimental and theoretical study of ultrathin Langmuir and Langmuir-Blodgett films of stearic and arachidic acids in contact with aqueous electrolyte solutions. The model included electrochemical and thermodynamic aspects of the adsorption of protons, calcium, and cadmium ions from solution to the film.

Ashley, K.R., Ball, J.R., Pinkerton, A.B., Abney, K.D., and Schroeder, N.C., Sorption behavior of pertechnetate on Reillex(tm)-HPQ anion exchange resin from nitric acid solution, Solvent Extr. Ion Exch., 12(2), 239–259 (1994). Distribution coefficients were obtained for pertechnetate adsorption on the nitrate form of the Reillex resin, and it was shown to be superior to a Dowex resin.

Bhagat, R.D. and Turel, Z.R., Radiochemical separation of thallium(I) using cerium(IV) molybdate as an ion-exchanger, Sep. Sci. Technol., 29(5), 663–669 (1994). Investigated the adsorption of Tl(I) under various operating conditions.

Bloomingburg, G.F. and Carta, G., Separation of protein mixtures by continuous annular chromatography with step elution, Biochem. Eng. J., 55(1), B19–B27 (1994). Continuous steady-state separation of mixtures of bovine serum albumin and hemoglobin obtained with the strong-acid macroporous resin S-Sepharose, and almost complete separation if appropriate selection of operating conditions.

Cabezon, L.M., Caballero, M., and Perez-Bustamante, J.A., Coflotation separation for the determination of heavy metals in water using colloidal gas aphrons systems, Sep. Sci. Technol., 29(11), 1491-1500 (1994).

Calvert, T.L., Phillips, R.J., and Dungan, S.R., Extraction of naphthalene by block copolymer surfactants immobilized in polymeric hydrogels, AIChE J., 40(9), 1449–1458 (1994).

Carlsson, F., Axelsson, A., and Zacchi, G., Mathematical modelling and parametric studies of affinity chromatography, Comput. Chem. Eng., 18(supplement), S657–S661 (1994). Model based on mass transfer and sorption rate constants and compared to lysozyme adsorption. The bead radius was found to be the most important parameter.

Carrere, H., Sochard, S., Bascoul, A., Wilhelm, A.M., and Delmas, H., Whey proteins extraction by fluidized ion exchange chromatography: Isotherms determination and process modelling, Food Bioprod. Process., 72(C4), 216–226 (1994).

Chang, R.M. and Lee, W.C., An affinity adsorbent derived from aminopropyl silica for serine protease chromatography, J. Chem. Technol. Biotechnol., 59(2), 133–139 (1994). Preparation of a silica-pABZ chromatographic-adsorbent which was used to adsorb trypsin, both flow rate and crude protein concentration influenced the chromatographic efficiency.

Chaudhary, A.J., Donaldson, J.D., Grimes, S.M., and Boddington, S.C., Heavy metals in the environment.

Part III. Anion exchange properties of poly-4-vinyl pyridine from acid chloride solutions, J. Chem. Technol. Biotechnol., 60(4), 353–358 (1994). Studied extraction of Cu, Ni, Co, Zn, and Cd ions from chloride solutions, efficiency shown to depend upon pH and solution composition. Metal extractive power of the resin increased as the solution metal chloride concentration increased.

Chiarizia, R., Horwitz, E.P., and Alexandratos, S.D., Uptake of metal ions by a new chelating ion-exchange resin. Part 4: Kinetics, Solvent Extr. Ion Exch., 12(1), 211–237 (1994). Determined the rate of uptake of several actinide ions and some transition-metal ions at tracer concentration level, from solutions of various compositions using a new chelating ion-exchange resin (Diphonix). See also Horwitz.

Chiarizia, R. and Horwitz, E.P., Uptake of metal ions by a new chelating ion-exchange resin. Part 6: Calculations on the effect of complexing anions on actinides, Solvent Extr. Ion Exch., 12(4), 847–871 (1994). Metal uptake data were analyzed by calculating the effect that complex formation in solution has on the overall metal uptake by the resin.

Ching, C.B., Chu, K.H., and Hidajat, K., Multicomponent separation using a column-switching chromatographic method, AIChE J., 40(11), 1843–1849 (1994). A cyclic process used to separate a three-component carbohydrate mixture with continuous feed supply.

Cortina, J.L., Miralles, N., Aguilar, M., and Sastre, A.M., Solvent impregnated resins containing di-(2-ethylhexyl) phosphoric acid. I. Preparation and study of the retention and distribution of the extractant on the resin, Solvent Extr. Ion Exch., 12(2), 349–369 (1994). SIRs prepared by adsorption of DEHPA on Amberlite XAD2 polymeric macroporous resin and studied as a function of both the nature of the solution and the extractant concentration used. The distribution of DEHPA between the aqueous and resin phases was determined as a function of both pH and loading of the extractant on the resin.

Cortina, J.L., Miralles, N., Aguilar, M., and Sastre, A.M., Solvent impregnated resins containing di-(2-ethylhexyl) phosphoric acid. II. Study of the distribution equilibria of Zn(II), Cu(II) and Cd(II), Solvent Extr. Ion Exch., 12(2), 371-391 (1994). Extraction of the ions from nitrate solutions at 25°C, distribution coefficient was determined as a function of both pH and extractant concentration in the resin phase. Results explained by assuming formation of metal complexes in the resin phase.

Davies, V.R., Troubleshoot ion-exchange equipment, Chem. Eng. Prog., 90(1), 63–71 (1994). Understanding problems (e.g. capacity loss, quality decline, pressure drop) and actions including resin fouling and cleanup procedures for water treatment.

de Lucas Martinez, A., Zarca Diaz, J., and Canizares, P.C., Ion-exchange equilibrium in a binary mixture: Models for its characterization, Int. Chem. Eng., 34(4), 486–497 (1994).

DeSilva, F., The ion exchange deal, Chem. Eng. (N.Y.), July, 86–88 (1994). Trading off ionic contaminants to produce ultrapure process water by ion exchange deionization.

El-Naggar, I.M., Abdel Hamid, M.M., and Aly, H.F., Kinetics and mechanism of isotopic exchange for $\mathrm{Co}^{2+}/{}^{*}\mathrm{Co}^{2+}$ in tin(IV) antimonate, Solvent Extr. Ion Exch., 12(3), 651–665 (1994). Determined the rate of isotopic ion exchange of Co ion in aqueous solution in a tin(IV) antimonate ion exchanger.

Fernandez, A., Rendueles, M., and Diaz, M., Co-ion behavior at high concentration cationic ion exchange, Ind. Eng. Chem. Res., 33(11), 2789–2794 (1994).

Fernandez, A., Rodrigues, A.E., and Diaz, M., Modelling of K-Na exchange in fixed beds with highly concentrated feed, Chem. Eng. J., 54(1), 17–22 (1994). Used a pore diffusion model for kinetics coupled with axial dispersion model for column hydrodynamics, and obtained a good prediction of fixed-bed batch experiments.

Giona, M., Adrover, A., Barba, D., and Spera, D., Simplified analysis of chromatographic-column dynamics, Chem. Eng. Sci., 49(4), 541–547 (1994). Analysis based on similarity equation (found experimentally) for outlet chromatograms of size-exclusion columns.

Gorry, M., Amin, P., and Richardson, D.W., Take the guesswork out of demineralizer design, Chem. Eng. (N.Y.), March, 112–118 (1994). Analyze your needs and specify all variables before soliciting vendor bids.

Grzywnowicz, K., and Lobarzewski, J., A purification method for specific serine proteases using one-step affinity chromatography, J. Chem. Technol. Biotechnol., 60(2), 153–160 (1994). Use of controlled pores and one-step process for microbial enzymes.

Guria, C., and Chanda, M., Shell-core models for ion-exchanger loading in finite bath: Sorption of aqueous sulphur dioxide on cross-linked poly(4-vinyl pyridine), Chem. Eng. Res. Des., 72(4), 503–512 (1994). Testing of two models to descibe the loading of ion-exchange resin beads.

Hairston, D., Markets for ion exchange resins, Chem. Eng. (N.Y.), June, 57–59 (1994). Reverse osmosis has reduced demand for ion exchangers, one suggestion is to develop countercurrent flow systems which are more cost effective.

Horwitz, E.P., Chiarizia, R., and Alexandratos, S.D., Uptake of metal ions by a new chelating ion-exchange resin. Part 5: The effect of solution matrix on actinides, Solvent Extr. Ion Exch., 12(4), 831–845 (1994). Investigated the influence of commonly occurring matrix constituents (complexing acids or cations) on the uptake of actinides. See also Chiarizia.

Ihsanullah, Optimization of various factors for the separation of technetium using anion-exchange resins, Sep. Sci. Technol., 29(2), 239–247 (1994). Investigated the effects of elution conditions, resin selection, and nitric acid concentration to optimize the separation.

Ihsanullah, Methods for the separation of technetium from ruthenium for inductively coupled plasma-mass spectrometry, Sep. Sci. Technol., 29(6), 781–797 (1994). Comparison of the decontamination factors of Ru and the percent recoveries for various processes, alternatives include precipitation, anion/cation exchange, and solvent extraction.

Kabay, N., Use of weak-acid cation-exchange resins Purolite C105(H^+) and Purolite C106(H^+) for the adsorption of UO_2^{2+}, Sep. Sci. Technol., 29(5), 679–683 (1994). The two resins showed rapid exchange kinetics in batch adsorption from nitrate solutions. The Purolite resin showed high uranyl ion loading in small-scale column operations and retained its capacity after five cycles, and it could be easily regenerated.

Kallrath, J., Schreieck, A., Brockmuller, B., Agar, D.W., Watzenberger, O., Falle, S., and Giddings, J.C., Simulation of chromatographic reactors, Comput. Chem. Eng., 18(supplement), S331–S335 (1994). Modeling of one-dimensional continuous-flow reactor with several gaseous components, and adsorption onto a solid catalyst.

Kitakawa, A., Yonemoto, T., and Tadaki, T., A mathematical model for the separation of amino acids using ion exchange chromatography, Food Bioprod. Process., 72(C4), 201-208 (1994).

McCoy, B.J. and Goto, M., Continuous-mixture model of chromatographic separations, Chem. Eng. Sci., 49(14), 2351–2357 (1994). Based on linear equilibrium partitioning or adsorption of the species in the stationary phase.

Mehablia, M.A., Shallcross, D.C., and Stevens, G.W., Prediction of multicomponent ion exchange equilibria, Chem. Eng. Sci., 49(14), 2277–2286 (1994). Model uses equilibrium data from binary systems to predict behaviour in multicomponent systems, also taking into account the non-idealities of the solution phase.

Mijangos, F. and Diaz, M., Kinetic of copper ion exchange onto iminodiacetic resin, Can. J. Chem. Eng., 72(6), 1028–1035 (1994).

Miyabe, K. and Suzuki, M., Mass-transfer phenomena on the surface of adsorbents in reversed-phase chromatography, Ind. Eng. Chem. Res., 33(7), 1792–1802 (1994).

Murty, B.N., Yadav, R.B., and Syamsundar, S., Preparation of high-purity zirconia from zircon: An anion-exchange purification process, Sep. Sci. Technol., 29(2), 249–259 (1994). Treatment of zirconium wet cake with the subsequent slurry passed through an anion-exchange resin for purification, the effluent is treated with sulphuric acid and then calcined to form zirconium dioxide.

Nash, K.L., Rickert, P.G., Muntean, J.V., and Alexandratos, S.D., Uptake of metal ions by a new chelating ion exchange resin. Part 3: Protonation constants via potentiometric titration and solid state 31P-NMR spectroscopy, Solvent Extr. Ion Exch., 12(1), 193–209 (1994). The resin exhibits exceptionally high affinity for polyvalent cations even from moderately acidic aqueous media.

Owen, R.O., McCreath, G.E., and Chase, H.A., Development and modelling of continuous affinity separations using perfluorocarbon emulsions, Food Bioprod. Process., 72(C1), 9–10 (1994). A countercurrent falling-bed type system using an emulsion of liquid perfluorocarbon droplets coated with PVA. Four-stage process includes adsorption, washing, elution and regeneration.

Parkinson, G., Chromatographers think BIG, Chem. Eng. (N.Y.), August, 30–33 (1994). Innovations improving both batch and continuous systems for industrial scale processes.

Pehlivan, E. and Yildiz, S., Column chromatography and kinetics of nucleosides and nucleic acid bases on immobilized nickel- and cobalt-CDAE-sporopollenin, Sep. Sci. Technol., 29(7), 887–895 (1994).

Plante, L.D., Romano, P.M., and Fernandez, E.J., Viscous fingering in chromatography visualized via magnetic resonance imaging, Chem. Eng. Sci., 49(14), 2229–2241 (1994). MRI and chromatographic peak shape analysis were used to study elution of bovin serum albumin and glycerol in size-exclusion chromatography columns.

Ray, A.K., Carr, R.W., and Aris, R., The simulated countercurrent moving bed chromatographic reactor: A novel reactor-separator, Chem. Eng. Sci., 49(4), 469–480 (1994). This reactor carries out chemical reaction and separation simultaneously in a fixed bed, performance is compared to a countercurrent moving-bed reactor.

Rifi, E.H., Leroy, M.J.F., Brunette, J.P., and Schloesser-Becker, C., Extraction of copper, cadmium and related metals with poly(sodium acrylate-acrylic acid) hydrogels, Solvent Extr. Ion Exch., 12(5), 1103–1119 (1994). Selectivity is as observed with liquid-liquid extraction of metal cations with fatty carboxylic acids (Pb > Cu > Cd > Zn > Ni = Co). Metal stripping from the gel by nitric acid washing. PAA hydrogel extraction allows Cd removal from aqueous solution down to 5 ppb.

Robinson, S.M., Arnold, W.D., and Byers, C.H., Mass-transfer mechanisms for zeolite ion exchange in wastewater treatment, AIChE J., 40(12), 2045–2054 (1994). A study of ion exchange from aqueous solutions using chabazite zeolite to better understand the basic mass transfer processes. Comparison of data with various models.

Sabharwal, K.N., Vasudeva Rao, P.R., and Srinivasan, M., Extraction of actinides by bifunctional phosphinic acis resin, Solvent Extr. Ion Exch., 12(5), 1085–1101 (1994). Extraction of U(VI), Am(III), Pu(IV), Np(IV) and Th(IV) from nuclear fuel cycle waste solutions is reported as a function of nitric acid concentration.

Save, S.V. and Pangarkar, V.G., A model for harvesting of microorganisms using colloidal gas aphrons, J. Chem. Technol. Biotechnol., 61(4), 367–373 (1994). A theoretical study and model development to predict the separation factor of a contactor.

Shaikh, A.M.H., Banerjee, S.S., and Dixit, S.G., Use of magnetic surfactants in the high gradient magnetic separation of essentially nonmagnetic calcite and barite, Sep. Technol., 4(3), 174–179 (1994). Using magnetic surfactants, manganese stearate and oleate, and investigated various parameters.

Shin, W.S. and Choi, S.J., Removal of Cu(II) from aqueous solution by oil-water interfacial emulsion technique with adsorbing colloids, Sep. Sci. Technol., 29(16), 2131–2141 (1994). Cu(II) was segregated into a compact emulsion between water and a water-immiscible oil phase using the adsorptive power of the interface. A surfactant removed the Cu(II).

Suchorebraya, S.A., Bortun, A.I., Alexandrova, V.S., and Strelko, V.V., On the studies of molybdenum(VI) sorption on titanium phosphate's ion exchangers, Solvent Extr. Ion Exch., 12(1), 173–192 (1994). Static and dynamic tests suggest an anion exchange mechanism for Mo(VI) sorption with ionites on amorphous titanium hydroxophosphate.

Sun, D., Brungs, M., Trimm, D., and Navratil, J.D., Separation and recovery of nickel and molybdenum using continuous rotating annular chromatography, Sep. Sci. Technol., 29(7), 831–843 (1994). Measured the effect of the feed flow rate and rotational speed of feed nozzle on performance.

Takahashi, Y. and Goto, S., Continuous separation of fructooligosaccharides using an annular chromatograph, Sep. Sci. Technol., 29(10), 1311–1318 (1994). Rotating feed nozzle and product collectors; oligosaccharides continuously separated from mono- and di-saccharide to obtain a lower calorie sweetener.

Tan, H.K.S. and Spinner, I.H., Multicomponent ion exchange column dynamics, Can. J. Chem. Eng., 72(2), 330–341 (1994). Formulation of simple model equations which consider different rate-control mechanisms for fixed-bed multicomponent ion-exchange processes. Can also be applied to liquid adsorption, and numerical examples for ion exchange applications are presented.

Trochimczuk, A.W., Horwitz, E.P., and Alexandratos, S.D., Complexing properties of diphonix, a new chelating resin with diphosphonate ligands, toward Ga(III) and In(III), Sep. Sci. Technol., 29(4), 543–549 (1994). Varibles included bead size, contact time, solution pH, and presence of competing cations. The resin displayed rapid rates of complexation and high selectivity under acidic conditions.

Tyc, I. and Green, B.R., Phenol-formaldehyde based weak-base resins for the recovery of gold, Solvent Extr. Ion Exch., 12(4), 817–830 (1994). Recovery of gold-cyanide with a weak-base resin requires loading at the natural pH of the leach liquor and stripping by an aqueous alkali. Investigated use of a phenol-formaldehyde polymer matrix and possible magnetic separation of the resin from the pulp.

Vamos, R.J. and Haas, C.N., Reduction of ion-exchange equilibria data using an error in variables approach, AIChE J., 40(3), 556–569 (1994). Method was tested for the ionic systems: Na-Cd, Na-Cu, and Cu-Cd, with a strong acid synthetic ion-exchange resin.

Wang, S.S., Lee, C.J., and Chan, C.C., Demulsification of water-in-oil emulsions by use of a high voltage ac field, Sep. Sci. Technol., 29(2), 159–170 (1994). Oil phase was liquid paraffin with surfactant, and the aqueous phase was deionized water with sulfuric acid. Studied the effects of emulsion structure and properties and demulsifying conditions on demulsification kinetics.

Whitley, R.D., Zhang, X., and Wang, N.H.L., Protein denaturation in nonlinear isocratic and gradient elution chromatography, AIChE J., 40(6), 1067–1081 (1994). Protein denaturation, common in hydrophobic adsorption systems, causes misinterpretation of adsorption mechanisms, interferes with analysis in analytical chromatography, and complicates the design of large-scale adsorption processes. A model is presented which isolates the effects due to denaturation from those due to mass transfer and intrinsic adsorption kinetics, and it is verified using protein gradient elution chromatography.

References

Ray, M.S. "Adsorptive and Membrane Separations: A Bibliographical Guide (1985–1989)," *Adsorpt. Sci. Technol.*, 7(1), 28–64 (1990).

Ray, M.S. "Adsorptive and Membrane-type Separations: A Bibliographical Guide (1991)," *Adsorpt. Sci. Technol.*, **8**(3), 114–133 (1991).

Ray, M.S. "Adsorption and Adsorptive Separations: A Bibliographical Update (1992–1993)," *Adsorption*, **1**(1), 83–97 (1995).

Ray, M.S. "Membranes and Membrane-type Separations: A Bibliographical Update (1992–1993)," *Sep. Purif. Methods*, **23**(1), 51–70 (1994).

Ray, M.S. "Distillation (1980–1990): A Bibliography," *Sep. Sci. Technol.*, **27**(1), 105–128 (1992).

Ray, M.S. "Equilibrium-Staged Separations: A Bibliography (1991)," *Sep. Sci. Technol.*, **28**(6), 1361–1378 (1993).

Ray, M.S. "Equilibrium-Staged Separations: A Bibliography Update (1992–1993)," *Sep. Sci. Technol.*, **29**(17), 2359–2385 (1994).

Ray, M.S. "Liquid-Liquid Extraction (1992–1993): A Bibliography Update," *Sep. Sci. Technol.*, **29**(18), 2541–2554 (1994).

Ray, M.S. "Supercritical Extraction (1980–1993): A Bibliographic Guide," *Sep. Sci. Technol.*, **29**(16), 2203–2213 (1994).

Ray, M.S. "Chemical Engineering Bibliography (1967–1988)," Noyes Publications, New Jersey, USA, 1990.

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