NOTATION

f = functional notation
p = mean pressure at any point
r = radial distance measured from axis of tube
R = radius of tube
t = time
u,v,w = instantaneous velocities fluctuations in x, r, and ϕ directions, respectively
U = mean velocity at any point
U_τ = friction velocity; $U_\tau^2 = -\nu\left(\frac{dU}{dr}\right)_{r=R}$
V,W = mean velocities in radial and azimuthal directions, respectively
x = axial direction
y = distance measured from the wall
y^+ = yU_τ/ν dimensionless distance
ν = kinematic viscosity
ϵ = eddy viscosity
ρ = density of fluid
ϕ = azimuthal direction

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Nonuniform Residence Times and the Production of Intermediates in Tubular Reactors

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The assumption of plug, or uniform, flow and the concomitant assumption of a uniform residence time is a frequent assumption in reactor engineering. This assumption may lead to gross errors, particularly if the product of interest is an intermediate in the reaction scheme. To illustrate this, consider the simple sequence

$$A \xrightarrow{k_1} R \xrightarrow{k_2} S \qquad (1)$$

and assume that R is the desired product. In this case

$$Y = \left[\frac{C_R}{C_{A_o}\left(\frac{k_1}{k_2 - k_1}\right)}\right] = e^{-k_1\theta} - e^{-k_2\theta} \qquad (2)$$

The value of the modified dimensionless concentration ratio, Y, becomes the plug flow value, Y_{pf}, when the contact time, θ, is taken as constant for all fluid elements passing through the reactor. If the distribution-of-residence times of fluid elements leaving the reactor is known as a function of position at the reactor exit, that is

$$\theta = f(\sigma) \qquad (3)$$

then Equations (2) and (3) may be combined to yield a mean value of the dimensionless concentration ratio across the reactor exit, Y_m.

For example, in a tubular reactor the velocity profile may be written

$$v = B\,(1 - \sigma^n) \qquad (4)$$

wherein B is chosen so that

$$\frac{V}{A} = v_m = 2B\int_o^1 (1 - \sigma^n)\sigma d\sigma \qquad (5)$$

regardless of the value of the exponent, n. From Equation (5) one finds

for $n = 2$, $B = 2\ v_m$ (the parabolic profile)
$n = 4$, $B = 1.5\ v_m$
$n = 8$, $B = 1.25 v_m$

Thus

$$\frac{Y_m(\sigma_c)}{Y_{pf}(\sigma_c)} = \frac{2\int_o^{\sigma_c} \sigma\left[e^{-\frac{K_1}{1-\sigma^n}} - e^{-\frac{K_2}{1-\sigma^n}}\right]d\sigma}{\sigma_c^2\left[e^{-K_1\frac{B}{v_m}} - e^{-K_2\frac{B}{v_m}}\right]} \qquad (6)$$

Equation (6) presents the ratio of the actual mean concentration of R in a tubular element about the axis having diameter $2\sigma_c$ to the concentration which would exist in this tubular element if the flow in it were uniform at a velocity equal to the integral mean value in the entire tube. The equation may be solved to examine the effect of the plug flow assumption if values of K_1, K_2, and n are available. This has been done for several sets of these constants, chosen for purely illustrative purposes. The results are shown on Figures 1 and 2. The former indicates the effect of sampling across the tube through various axisymmetric element sizes, and the latter illustrates the effect on the average concentration issuing from the entire tube cross section

INFORMATION RETRIEVAL*

The effect of packing on a fluidized bed, Sutherland, J. P., George Vassilatos, Hiroshi Kubota, and G. L. Osberg, **A.I.Ch.E. Journal, 9,** No. 4, p. 437 (July, 1963).

Key Words: Fluidization-8, Gas-1, Air-1, Solid-1, Glass Beads-1, Silica-1, Packing-6, Spheres-6, Saddles-6, Screens-6, Cylinder-6, Pressure Drop-7, Velocity-7, Expansion-7, Slugging-7, Heat Transfer-7.

Abstract: The properties of gas-fluidized beds containing various packings such as spheres, saddles, and screen cylinders have been examined. Measurements have been made of pressure drop, minimum fluidization velocity, and bed expansion for a range of particle-packing combinations. Preliminary measurements of heat transfer rates in fluidized-packed beds have also been made.

Separation of liquids by mass diffusion, Shuck, F. O., and H. L. Toor, **A.I.Ch.E. Journal, 9,** No. 4, p. 442 (July, 1963).

Key Words: Mass Diffusion-8, Mass Transfer-8, Diffusion-8, Multicomponent-8, Transport-8, Separation Factor-8, Yield-8, Liquids-9, Methyl Alcohol-1, η-Propyl Alcohol-1, Isobutyl Alcohol-1, Flow/Separating Agent-6, Pore-Size Distribution-6, Separation Factor-7, Yield-7, Flow Cell-10, Diaphragm-10, Theory-10, Multicomponent Diffusion-.

Abstract: Mass diffusion studies were carried out in a diaphragm diffusion cell with the liquid system methyl alcohol, n-propyl alcohol, isobutyl alcohol. Experiments were conducted over a wide range of separating agent counterflow. The separation factor was approximately doubled and the yield decreased three orders of magnitude when the counterflow was increased one order of magnitude. Using the four ternary diffusion coefficients for the system and a diaphragm geometry based on previous calibration, the concentration and separation factors could be predicted within the range of experimental error. The theory indicates that at high counterflow considerably larger separation factors would be obtained if the diaphragm were uniform.

Limitations on a generalized velocity distribution, Brodkey, Robert S., **A.I.Ch.E. Journal, 9,** No. 4, p. 448 (July, 1963).

Key Words: Power Law-6, Pressure Drop-6, Radius-6, Viscosity-6, Density-6, Power Series Velocity Distribution-7, Eddy Diffusivity-7, Turbulent Velocity Distribution-8, Transition Velocity Distribution-8, Newtonian Fluids-9, Non-Newtonian Fluids-9, Pipes-10, Channels-10, Limitations-.

Abstract: The usefulness of the Pai power series representation for the velocity distribution has been limited because of the lack of knowledge about the functional dependence of the empirical constant on the Reynolds number. Correlations are given for this constant for both Newtonian and non-Newtonian materials; however, certain limitations are found as a result of the actual velocity distribution calculations.

The interpretation of model experiments for the displacement of fluids through porous media, Heller, J. P., **A.I.Ch.E. Journal, 9,** No. 4, p. 452 (July, 1963).

Key Words: Flow-1, Darcy-1, Porous Media-5, Displacement-7, Dispersion-7, Scaling-8, Instability-8, 0.1 Field-9, Reservoir-9, Model-9.

Abstract: The engineering problem of oil recovery by solvent or water flooding is stated in general terms. Several models have been employed for the analysis of these problems. In addition to those involving actual fluid flow through porous material, various semi-models have been used.

The physical processes occurring in prototypes and models are compared, and their mathematical representation examined. The mechanism of mixing of miscible fluids in the prototype porous media are diffusive and convective. Both of these are affected by the microscopic properties and uniformity of the matrix. If the fluids are immiscible the microscopic details of the displacement are dominated by the Haines jumps at the interfaces. Also, if the viscosity or density of the displacing and displaced liquids differ, a regenerative situation becomes possible which may influence markedly the gross mixing process. Although similar phenomena are operative in fluid-flow models, it is not always true that their relative importance is the same; thus the output behavior of model and prototype may not be similar. The areas of usefulness of various displacement model experiments are noted, and cautionary rules are prescribed for their interpretation.

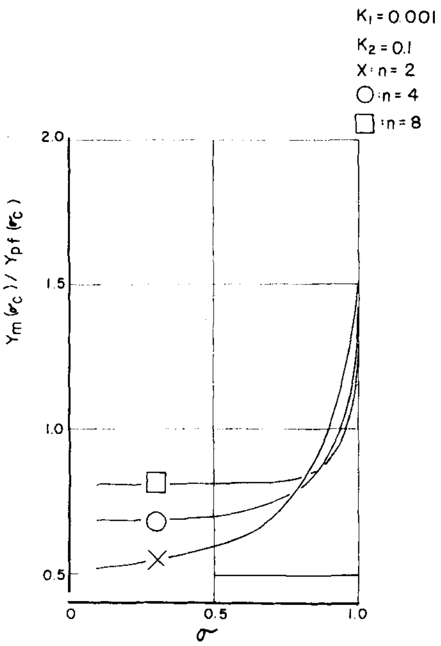

Fig. 1. Mean conversion vs. radial position (three flow conditions).

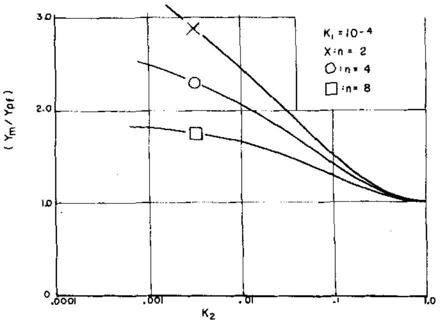

Fig. 2. Mean conversion vs. K_2 (full tube-three flow conditions).

of various profile shapes and of various values of the velocity constant for the undesirable second reaction. It is apparent the plug flow assumption becomes acceptable as the value of the second velocity constant increases in comparison to the first and, of course, as the profile becomes flatter. This latter condition is of importance in the case of highly turbulent flows and possibly in the case of some non-Newtonian flows.

There is nothing new in this presentation, the results are implicit in much of the literature dealing with chemical reactors. The magnitude of the error possible when the plug flow assumption is used in situations wherein an intermediate product is of interest seems worthy of note.

NOTATION

A = cross-sectional area
B = constant, see Equation (4)
C_i = concentration (moles/liter) of i
k_i = rate constant (time^{-1}) of step i

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* For details on the use of these key words and the A.I.Ch.E. Information Retrieval Program, see **Chem. Eng. Progr., 57,** No. 5, p. 55 (May, 1961), No. 6, p. 73 (June, 1961); **58,** No. 7, p. 9 (July, 1962).

K_1 = a constant = k_1L/B
K_2 = a constant = k_2L/B
n = constant, see Equation (4)
r = radial position
R = tube radius
Y = modified dimensionless concentration ratio
Y_m = dimensionless concentration ratio across the reactor exit
v_m = $\frac{V}{A}$ = integral mean velocity
V = volumetric flow rate
θ = contact time
σ = dimensionless position variable = $\frac{r}{R}$

Subscripts

o = initial value
pf = plug flow value
m = mean value
c = a particular radial position $\leqq 1$

(*Continued from page 436*)

and challenge the student. Second, the arrangement of topics in the book in many places does not reflect the logical organization of the subject material: in Chapter 1 we find "Scalar Product" as a section heading under "Matter and its Atomic Nature"; in Chapter 13, we find "Third Law of Thermodynamics" as a section heading under "Thermodynamic Changes in Chemical Reaction." Third, many topics are introduced with no word to the reader as to the possible application; for example, three pages are devoted to quantum mechanical "tunneling" with no mention of the physical applications (for example alpha-particle decay). Four, too often derivations are given without proper words of caution as to the restrictions which are inherent in the procedure; for example, in Chapter 6 in the discussion of the LCAO methods far too little is said about the assumptions involved, and in Chapter 9, the reader is not told under what conditions the factorization of the polyatomic molecule partition function might not be allowable. These faults will make the book difficult to use for self-study, and will require that instructors be particularly careful in helping their students interpret some of the material.

This book has kept up the tradition of its predecessors by having many illustrative examples in the text and a large collection of homework problems. Answers to many of the latter are given at the back of the book.

The reviewer does not agree with the way the quantum mechanical discussion is presented; he would have preferred a postulational approach with a minimum of historical background. Also the reviewer has reservations about the mode of presentation of the material on kinetic

INFORMATION RETRIEVAL

Continuous propagation of microorganisms, Fredrickson, A. G., and H. M. Tsuchiya, **A.I.Ch.E. Journal, 9,** No. 4, p. 459 (July, 1963).

Key Words: A. Propagation-8, Stability-8, Microorganisms-2, Fermenters-10, Continuous-, Steady State-, Analysis-. B. Analysis-8, Processes-1, Stochastic-Multiplication-, Cells-, Microorganisms-, Propagation-2, Cultures-, Microorganisms.

Abstract: The growth of a pure culture of microorganisms in a steady state fermentor is studied analytically. Processes involved in the life cycle of a single microbial cell form the basis of the treatment. Equations are developed which relate stochastic growth and reproductive processes on the cellular level to the behavior of the cell population. These equations are used to predict culture age distribution and metabolic rates in the steady state. The stability of the steady state is considered finally.

Gas-liquid kinetics: the absorption of carbon dioxide in diethanolamine, Nunge, Richard J., and William N. Gill, **A.I.Ch.E. Journal, 9,** No. 4, p. 469 (July, 1963).

Key Words: Diethanolamine-1, Carbon Dioxide-1, Mixing-6, Temperature-6, Reaction Rate-7, Kinetics-8, Absorption-8, Reaction Order-9, Mechanism-9, Reactor-10, Ethanolamines-, Henry's Law-, Stirred-.

Abstract: The absorption of carbon dioxide in pure diethanolamine was studied in a gas-liquid stirred reactor at 85°, 95°, and 105°F. Experimental data were consistent and reproducible.

The experimental data were correlated with the simplified equation by both integral and differential methods and indicate that the reaction follows a third-order rate equation: first order in carbon dioxide and second order in diethanolamine. A mechanism explaining the observed order is described.

Effects of solute purity, temperature, and surfactants on solid-liquid mass transfer, Ghosh, D. N., and D. D. Perlmutter, **A.I.Ch.E. Journal, 9,** No. 4, p. 474 (July, 1963).

Key Words: Mass Transfer-8, Coefficients-7, Solute Purity-6, Temperature-6, Surfactant Concentration-6, Cinnamic Acid-1, Water-5, Correlations-9, Stirred Transfer Cell-10, Solid-Liquid-9.

Abstract: The mass transfer coefficients for a process of solid dissolution vary with solute purity. The Reynolds and Schmidt number exponents which are used in the usual dimensionless group correlations also depend on solute purity, even over a narrow range of only several percent. The effect of temperature on the mass transfer process may be attributed to Schmidt-number variation. Surfactants may increase or decrease the transfer rate or leave it unchanged; specific behavior depends on the solute purity as well as the concentration and ionic nature of the surfactant.

Performance of packed columns VII. The effect of holdup on gas-phase mass transfer rates, Shulman, H. L., C. G. Savini, and R. V. Edwin, **A.I.Ch.E. Journal, 9,** No. 4, p. 479 (July, 1963).

Key Words: Mass transfer-8, Absorption-8, Vaporization-8, Liquid Holdup-6, Water-5, Packings-10, Column/Packed-10, Methanol-5, Mass Transfer-7.

Abstract: To account for the differences in the gas-phase mass transfer coefficients obtained by the use of vaporization and absorption techniques, data were obtained for ring and saddle packings in a 12-in. diam. column employing water vaporization and methanol absorption. The ratio of the vaporization to absorption coefficient, corrected for differences in diffusivity, is found to be directly proportional to the ratio of the total holdup to the operating holdup thus confirming the proposed model in which the effective interfacial area for each type of operation is proportional to the holdup of the liquid active for that operation.