DISCUSSION

The results from the analysis reveal that, for our absorption column, dispersion effects are small over the range of operating conditions reported. Thus, the plug-flow assumption is valid in this case, and the analysis of the mass transfer coefficient is simple. Often, simplifying assumptions are presented without justification. This new experiment provides students with the opportunity to verify the assumptions that are used to derive the well-known result for the mass transfer coefficient in a packed column. In this paper we chose to present the differential model as the one most closely representing the physical characteristics of the flow pattern through the packing. The students are not limited, however, to this model to explain deviations from plug flow. Levenspiel,[1] Lo, *et al.*,[4] and King[3] describe several models used for this purpose. For small-to-intermediate extents of dispersion, a tanks-in-series model with back flow is commonly employed. Other models use recirculation, back mixing, dead volumes, and combinations of these in conjunction with the tanks-in-series model. These models are much more cumbersome, and we found the dispersion and the tanks-in-series models adequate for our purposes.

The apparatus described here was designed at UCSB and was constructed by an off-campus contractor at a cost of $12,000. The electronic instrumentation was an additional $6,000. The apparatus is used in each of our required two-quarter sequence courses in Chemical Engineering Laboratory. In the first-quarter course, steady-state data are taken to determine mass transfer coefficients, and in the second quarter the axial dispersion measurements described here are carried out.

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NOMENCLATURE

- a = interfacial area per unit volume, ft^{-1}
- A = cross-sectional area of empty column, ft^2
- c_i = integration constants, Eqs. (33) and (34)
- C = concentration, $lbmol \cdot ft^{-3}$
- $\mathbf{C}$ = normalized concentration, s^{-1}
- d_i = roots to characteristic equation, Eq. (32)
- E = dispersion coefficient, $ft^2 \cdot s^{-1}$
- G = volumetric gas flow rate, $ft^3 \cdot hr^{-1}$
- h = column height, ft
- K_L = liquid phase overall mass transfer coefficient, $lbmol \cdot ft^{-2} \cdot s^{-1}$
- L = volumetric liquid flow rate, $ft^3 \cdot hr^{-1}$
- m = equilibrium coefficient
- N = dimensionless group, Eq. (28), or number of data pairs
- n = number of tanks in tanks-in-series model
- P = pressure of the gas phase, atm
- Pe = Peclet number, Eq. (27)
- Q = total tracer response integrated over all time
- t = time, s
- u = linear velocity of the liquid, $ft \cdot hr^{-1}$
- w = dimensionless length, z/h
- X = $x_e - x$
- x = mole fraction of solute in the liquid phase
- y = mole fraction of solute in the gas phase
- z = axial coordinate, ft

- ***Greek Symbols***
  - σ = standard deviation
  - θ = dimensionless time
  - τ = mean residence time, s
- ***Subscripts***
  - e = equilibrium condition
  - f = feed condition
  - h = top of column
  - G = gas phase
  - L = liquid phase
  - lm = log mean driving force, Eq. (36)
  - 0 = bottom of column

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ChE book review

SEPARATIONS IN CHEMICAL ENGINEERING: EQUILIBRIUM STAGED OPERATIONS

by Phillip C. Wankat; Prentice Hall Publishing Co., 113 Silvan Ave., Englewood Cliffs, NJ 07632; 707 pages, $47.50 (1988) (Formerly published by Elsevier Publishing Co.)

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Engineering analysis and design of the classical separation methods of distillation, absorption, and liquid-liquid extraction are covered in depth by Wankat's *Separations in Chemical Engineering: Equilibrium Staged Operations.*

This text has some excellent pedagogical qualities. It is easy to read, has clear detailed descriptions, and follows a logical progression which gradually builds on previous concepts. The development of problem-solving skills is emphasized throughout the text using a systematic approach (a modification of the strategy developed at McMaster University*) which follows six steps: 1) define the problem; 2) explore or think about it; 3) plan; 4) do it; 5) check; and 6) generalize. To reinforce the utility of this method, the example problems in the text are worked according to this procedure. This text would be very suitable for self-study. The level of sophistication is appropriate for sophomores, but may not appeal to senior-level students. A knowledge of calculus, material and energy balances, and phase equilibria is recommended. Mass transfer concepts are introduced only in Chapter 19 within the context of packed tower design.

Many problems are provided at the end of each chapter, some of which involve writing computer programs. They are divided into several categories: Discussion Problems, Generation of Alternatives, Derivations, Problems, More Complex Problems, Problems Requiring Other Resources, and Open-Ended and Synthesis Problems (a solution manual is available). A practical discussion of equipment design which includes correlations and heuristics is enhanced by some well-chosen photographs. However, the book lacks an Appendix containing the usual data tables necessary to make it a useful reference for design.

The text is comprised of nineteen chapters, the first fourteen of which are devoted to distillation. Chapter 1 defined an equilibrium stage process and a unit operation, and introduces the approach to problem solving. Vapor-liquid equilibria are reviewed in Chapter 2, including the conventional xy, Txy, and Hxy graphical representations followed by dew point and bubble point calculations.

Rigorous calculations for flash distillation are presented in Chapter 3 for binary and multicomponent systems necessary for sizing the flash drum. Column distillation is initially introduced as a cascade of flash vaporizations in Chapter 4. Photographs of actual equipment convey a sense of the size and scale of a distillation tower. Possible flow regimes within the tower and their effect on the efficiency of separation are described. The concept of external material and energy balances is also introduced in Chapter 4.

Internal, stage-to-stage calculations are presented in Chapter 5, according to the Lewis method, which assumes constant molal overflow. Chapter 6 covers the McCabe-Thiele graphical analysis, including many variations on the theme such as open steam, partial condensers, total reboilers, side streams, and intermediate reboilers and condensers. Limiting conditions, efficiencies, subcooled reflux, and superheated boil-up are also discussed.

Building upon this knowledge of binary systems, multicomponent distillation is described in the next

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three chapters. Chapter 7 details the tedious hand calculations performed for the design of multicomponent systems. This provides motivation for the development of a computer code to implement the methods of Lewis-Matheson and Thiele-Geddes in Chapter 8 and the shortcut methods derived by Fenske, Underwood, and Gilliland in Chapter 9.

Complex distillation methods which handle azeotropic, extractive, and two-pressure distillation are covered in Chapter 10. Chapter 11 presents a switch from continuous operation to methods associated with batch distillation using the Rayleigh equation. Chapter 12 contains information regarding staged column design including column diameter, efficiency, and tray size, while packed column design is discussed in Chapter 13. Consideration of economic trade-offs between various design options leads to a more detailed discussion of economics in Chapter 14, which addresses such topics as capital and operating costs, energy conservation, and column sequencing.

The processes of absorption and stripping are analyzed in Chapter 15, using the Kresmer equations as well as the McCabe-Thiele method. Immiscible extraction in Chapter 16 is also discussed in the context of the McCabe-Thiele analysis. For extraction involving dilute mixtures, the Kresmer equations are shown to be appropriate. Example calculations for crossflow operations are also included.

In Chapter 17, generalizations of the McCabe-Thiele analysis are applied to washing, leaching, supercritical fluid extraction, and three-phase systems. Table 17.1 effectively summarizes the relationships between the various separation processes in terms of McCabe-Thiele analysis.

Extraction for partially miscible systems with triangular diagrams and the lever rule is analyzed in Chapter 18, and Chapter 19 introduces mass transfer concepts for design of packed beds, mass transfer coefficients, sum of resistances, and tray efficiencies leading to HTU-NTU analysis for absorbers and strippers. Note that rate-limited processes, including adsorption, chromatography, electrophoresis, and membrane separations, are included in a sequel to this text entitled *Mass Transfer Limited Separations.*

The predominant concept in this text is the McCabe-Thiele analysis. Distillation, absorption, and extraction processes are treated in terms of McCabe-Thiele diagrams. This approach emphasizes the analogies between these separation processes, which is very instructive from a pedagogical point of view. But it consequently results in a very narrowly focused book. The narrow focus is my major criticism of this text. Our current curriculum combines a study of equilibrium-staged separation processes with fundamentals of mass transfer and rate-controlled separation processes within a single course during the second semester of the third year. This text would only cover about one-third of the material for the course and therefore would require either additional texts or other supplementary material for the remaining topics. Since students are generally opposed to purchasing more than one text for any given course, I see this book filling the role of a supplementary text to complement a primary text that covers a broader range of material. The other alternative would be to devote an entire course to equilibrium-staged operations, for which this book would be an excellent text. However, with the chemical engineering curriculum already overloaded, it is difficult to justify creation of a new course for this single topic.

One additional minor criticism regards the appearance of the print. The type is not particularly easy on the eye since the book has evidently been produced in camera-ready form on a low-resolution (by printing standards) printer. ❒