ChE letter to the editor

Dear Editor:

In their recent article titled "An Experiment to Characterize a Consolidating Packed Bed" (*CEE,* 31(3), p. 192, 1997), Gerrard, Hackborn, and Glass misinterpret the Kozeny equation for low gas flow through packed beds and consequently arrive at an incorrect result.

The Kozeny equation as written by these authors is

$$\Delta p = 5a^2(1-\varepsilon)^2 \mu h v / \varepsilon^3 \tag{1}$$

(Nomenclature and numbering of equations follow those of the article criticized, with the addition that numbers assigned to *corrected* equations have the letter "a" appended to them.) In this form of the equation, the term a signifies the specific surface of the particles in the packed bed, *i.e.,* particle surface area/particle volume, and is independent of the bed consolidation (assuming rigid particles). Therefore, in the authors' terminology,

$$a = a_o \tag{3a}$$

The specific surface of the packed bed, particle surface area/bed volume, is given by the product $a(1-\varepsilon)$. Unfortunately, the authors incorrectly assume that a alone signifies the specific surface of the bed, and hence they write

$$a = a_o h_o / h \tag{3}$$

which is *incorrect* for a as used in Eq. (1).

If instead of Eq. (3), one correctly substitutes Eq. (3a) and the authors' Eq. (2),

$$\varepsilon = 1 - \frac{(1-\varepsilon_o)h_o}{h} \tag{2}$$

into Eq. (1), the result is

$$\Delta p = \frac{5a_o^2 h_o^2 (1-\varepsilon_o)^2 \mu v h^2}{\{h-(1-\varepsilon_o)h_o\}^3} \tag{4a}$$

or

$$\Delta p = kvh^2 / (h-G)^3 \tag{5a}$$

where

$$k = 5a_o^2 h_o^2 (1-\varepsilon_o)^2 \mu \tag{6a}$$

and

$$G = (1-\varepsilon_o)h_o \tag{7}$$

Rearranging Eq. (5a) gives

$$\left(h^2 v / \Delta p\right)^{1/3} = k^{-1/3}h - k^{-1/3}G \tag{8a}$$

Thus it is $\left(h^2 v / \Delta p\right)^{1/3}$, and not $(v/\Delta p)^{1/3}$, that should be plotted against h in order to linearize Eq. (5a). That approximate linearlization was actually obtained by plotting $(v/\Delta p)^{1/3}$ instead of $\left(h^2 v / \Delta p\right)^{1/3}$ against h can be attributed to the fact that the maximum decrease in $h^{2/3}$ for the experiments performed was only $1-(0.41/0.61)^{2/3} = 23\%$.

The authors should note that if they were to substitute their Eq. (9),

$$a = 6(1-\varepsilon)/D_p \tag{9}$$

into Eq. (1), the right-hand side of the latter equation would then contain $(1-\varepsilon)^4$ in the numerator, which is clearly incorrect. The error arises from the misinterpretation of a, which is *not* the packed bed specific surface given by Eq. (9), but the particle specific surface given by

$$a = \pi D_p^2 / (\pi/6) D_p^3 = 6/D_p \tag{9a}$$

(Alternately, if we define a as the authors have done, then the $(1-\varepsilon)^2$ term in Eq. (1) would disappear.)

Professor Norman Epstein
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Dear Professor Epstein:

Thank you for pointing out the correction, which makes the fit even better.

Professor Mark Gerrard

ChE book review

Batch Distillation
Simulation, Optimal Design and Control

by *Urmila M. Diwekar*

Published by *Taylor & Francis, 1101 Vermont Ave., N.W., Suite 200, Washington, DC 20005; 211 pages including index; $59.95 (1995)*

Reviewed by
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Batch processes, and batch distillation in particular, are understudied in universities. The typical undergraduate separations textbook devotes a short chapter to batch distillation, and typical coverage in courses (*CEER*, **28**, p 15, 1994) is from one to three class periods. The average graduate student does no additional study of batch distillation. Yet, batch distillation is an increasingly important separation method in industry, and there is significant interest in batch distillation research.

Batch Distillation, which is "primarily designed to serve as a textbook for a graduate course," is very timely. The companion software MultiBatchDS (education edition from CACHE Corp.) was not available and is not reviewed here. A review of the book and the software from a consultant's viewpoint was recently published (*Chem. Engr. Progr.,* p. 77, June 1997).

If the software is available, this would be a good text for a graduate-level course. There are 38 homework problems in the book, which is probably sufficient for the first time the course is offered. With the exception that packed columns are not covered, the coverage is broad and most topics of interest are included.

Chapters 1 and 2 introduce batch distillation and analyze binary systems. These two chapters are a good resource for professors and undergraduate students, but some professorial guidance will be needed. For example. Eq. (1.6) and

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of macropore size and operating pressure on the macropore resistance. These questions guide their thoughts to the following important points:

- For a micropore-controlled system, a reduction in the macroparticle size should not affect the mass transfer kinetics. Hence, when the k value remains unaffected by a change in the particle size, it serves as clear proof that the axial dispersion and macropore resistance are practically negligible. On the other hand, a variation in values estimated from experimental runs with different particle size and/or at different velocities will indicate that the secondary resistances are not negligible and their contributions have not been properly estimated.
- The importance of Knudsen diffusivity depends on the effective macropore size and is independent of pressure, whereas molecular diffusivity is inversely proportional to pressure and may affect the overall transport rate at a higher pressure.

CONCLUSIONS

This laboratory exercise introduces the students to the calculations of equilibrium and kinetic parameters for an adsorption separation process. The use of a dynamic model for the extraction of the mass transfer parameter provides a useful visualization of the role of this parameter on process performance. The simulation model can also be effectively used to illustrate in detail the numerical solution of a system of coupled partial differential equations. The consistency of results obtained by different groups is encouraging. Equilibrium capacity and mass transfer resistance of the chosen system are well suited for completing the required number of runs and necessary computations in one standard laboratory session of six hours.

REFERENCES

1. Lapidus, L., and N.R. Amundson, *J. of Phy. Chem.*, **56**, 984 (1952)
2. Sherwood, T.K., R.L. Pigford, and C.R. Wilke, *Mass Transfer*, McGraw-Hill, New York, NY; Chap. 2
3. Ruthven, D.M., *Principles of Adsorption and Adsorption Processes*, Wiley Interscience, New York, NY, Chap. 7 (1984) ❒

BOOK REVIEW: *Batch Distillation*

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Example 1.2 are easily misinterpreted. And there is a technical mistake in the calculation of the heat to the reboiler in Eqs. (2.13) and (2.17). The author ignores the energy required to vaporize the distillate product in the reboiler. Equation 2.13 should be $Q_R = \lambda(R+1)D$.

The graduate-level material starts in Chapter 3, "Column Dynamics," which derives the unsteady mass and energy balances. Then error, stability, and a summary of numerical integration techniques are presented. The need for an integration technique capable of handling stiff equations is clearly illustrated in Example 3.1. The chapter is completed with sections on start-up and approximate models. There are some parts that will confuse students. For example, the numbering of stages in Figure 3.1 does not agree with the equations, and derivation of Eq. (3.44) requires assumptions not mentioned in the text.

The author is clearly an expert on the application of shortcut (Fenske-Underwood-Gilliland) methods to batch distillation. Readers are told to "be careful in choosing the appropriate value for the light key and heavy key for successful use of this method," but how to be careful is not explained. This and other small mysteries will cause confusion. The modified shortcut method developed next requires lumping a number of plates into compartments. Other than comparison with an exact solution, no guidance is given on how to select the number of plates in each compartment. The last section on the hierarchy of models in the simulator will be very helpful to students using the simulator.

Chapter 5, "Optimization," describes objective functions, degree of freedom analysis, feasibility, and the general framework of solution methods. This chapter is quite general and would benefit greatly from numerical examples. Chapter 6 on optimal control problems builds on Chapter 5. This chapter would also benefit from numerical examples in addition to the derivation examples.

The last chapter analyzes azeotropic systems and columns with a middle vessel. Since most students will be unfamiliar with the analysis of steady state azeotropic distillation, more details on residue curve maps and synthesis of batch distillation systems would be welcome. The shortcut method is extended to binary azeotropic systems and simple ternary systems. Extension to more complicated ternary azeotropic systems would be welcome.

The index appears to be quite well done. An author index would be appreciated. The reference lists at the end of each chapter appear to include all the important historical and recent papers. The nomenclature list is quite complete, and the tables that summarize the equations after each theoretical development are helpful. The type is easy to read and there appear to be few typographical errors. Unfortunately, the figures are not of professional quality and are difficult to interpret. Many of the figures have multiple curves that are not labeled. When two theories are compared on the same figure, the reader needs to guess which is which. The curves are not smooth and it is often unclear if the wiggles are real or due to the plotting routine.

Every chemical engineering department should obtain a copy for their library's reserve section. Chapters 1 and 2 will be helpful as a reference for undergraduates doing laboratory or design projects on binary batch distillation. The remainder of the book will help graduate students and professors who occasionally encounter multicomponent batch distillation problems. ❒