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Principles and Modern Applications of Mass Transfer Operations

By Jaime Benitez, Wiley, New York, 2002, 499 pp., $89.95.

Professor Benitez's book is a new entry into the market of textbooks intended for use in courses that teach chemical engineering separations, staged operations, and continuous contacting mass-transfer processes. Familiar texts in this group are *Separation Process Principles* (Henley and Seader, 1998), *Mass Transfer Operations* (Treybal, 1980), the pair of books by Wankat (1988, 1990), *Equilibrium Staged Separations* and *Rate Controlled Separations* and *Separations Processes* by King (1980). Of these, this new book is closest to Treybal's book in topics and approach.

Principles and Modern Applications of Mass Transfer Operations is very much focused on the traditional chemical process industries. Chapter titles are, "Fundamentals of Mass Transfer, Convective Mass Transfer, Interphase Mass Transfer Equipment for Gas-Liquid Mass-Transfer Operations, Absorption and Stripping, Distillation, and Liquid-Liquid Extraction." Each major section of the book has learning objectives, which certainly benefit the students and perhaps the instructor! A key feature of the book, which separates it from the other texts mentioned above, is the incorporation of *Mathcad* for both example problems and homework questions. A library of *Mathcad* programs for solving the Maxwell-Stefan equations, packed column calculations, sieve-tray design, binary distillation problems by McCabe-Thiele method, and multistage crosscurrent extraction is given in the appendices. These programs enable students to obtain useful solutions with less effort, as well as allow them to explore the different variables or parameters. The wide availability, low cost, and ease of use of *Mathcad* allow it to be the modern equivalent of "back of the envelope" calculations, which can be refined, if necessary, using full-scale process simulators.

The first chapter, "Fundamentals of Mass Transfer," introduces the subject formally and in significant detail covering essentially all topics of diffusive mass transfer necessary for study using this book. The author often goes beyond the standard treatment. For example, after definitions of concentration and fluxes, the Stefan-Maxwell relations are given as the fundamental model for molecular diffusion. This is a nice feature, contrasting most of the competing books, which start with Fick's Law. By starting with Stefan-Maxwell equations, such problems as chemically facilitated transport, membrane transport, (apparent) paradoxes of diffusion caused by pressure differences, and multicomponent diffusion in complex mixtures, can be described. The 17 examples in this 65 page chapter include such topics as dissolution, and effective diffusivity in a multicomponent gas mixture (related to ammonia cracking) and in a mixture of solvents. The standard problems, simple binary diffusion through a stagnant film and equimolar counterdiffusion are also included. 31 homework problems are given most with (just) the numerical answer.

The second chapter, "Convective Mass Transfer," begins by relating mass transfer in turbulent flow to the previously-solved diffusion through a stagnant film and thus defines the "F" mass-transfer coefficient in an identical fashion to Treybal (1980). Sections on dimensional analysis, and mass- and heat-transfer analogies follow (including a reprinting of Table 3.2 from Treybal comparing dimensionless groups in which we find, surprisingly, in this world of electronic publishing that the local mass-transfer coefficients k_c and k_y are copyrighted!).Through the 14 examples, 53 pages, and 26 homework problems, the author does a very good job explaining which type of mass-transfer coefficient to use for many situations and how to find a value for it.

The third chapter, "Interphase Mass Transfer," contains a very brief treatment of phase equilibria including Raoult's Law, a "modified form of" Raoult's Law (that is, activity coefficients are written for the liquid phase), Henry's Law, and K-factors for liquid-liquid systems. Given the overriding importance of phase equilibria on all of the problems in this book and all mass-transfer operations, it might have been better if a more comprehensive exposition on the topic was done. Interphase mass transfer is discussed starting with two-resistance theory; overall mass-transfer coefficients are introduced. Another couple of sections are devoted to gas side controlled and liquid side controlled situations. This is the end of the formal treatment of mass transfer and, if carefully studied, students would know rules and procedures for getting mass-transfer coefficients for a very large fraction of the situations in the process industries. However, they might have gained more understanding and ability to apply these concepts in new situations if the various coefficients and driving forces had been compared numerically and algebraically (such as to *show* that the logarithmic driving force is equivalent to a linear driving force for sufficiently dilute systems). Also, there is no discussion of mass transfer in terms of the differential transport equations; the word "boundary-layer" does not appear in the index and apparently not in the book. The rest of this chapter is a first cut at the basic procedure using mass balances and equilibrium lines for solving continuous contacting operations and equilibrium staged operations. The mass balance is used to get an operating line and the correspondence between the diagram and a real device is discussed as is the concept of minimum flow rates caused by intersection of the equilibrium and operating lines. For staged operations, the basic stepping construction is introduced. A total of 10 examples and 27 homework problems are included.

The next chapter, "Equipment for Gas-Liquid Mass Transfer Operations," describes gas-liquid packed towers extensively; bubble columns and tray columns are also included with some discussion of tray design. Enough information is given, for example, to choose packing size or, say, tray spacing, for many situations.

The title of Chapter 5 is "Absorption and Stripping". The topic is first discussed for tray columns and then for packed columns. Thermal effects are also considered for both tray and packed towers. The chapter ends with an elaborate solution that takes 8 pages for adiabatic ammonia absorption in a packed tower. 26 homework problems are included.

"Distillation" is the topic of the sixth chapter starting with flash, which is followed by simple distillation (but only for a single stage, which must leave students wondering why anyone would use it). Next comes the McCabe-Thiele method, which is covered extensively including using it with the Kremser method to deal with a large number of trays. Also, a *Mathcad* program is supplied for solving McCabe-Thiele distillation. The Ponchon-Savarit Method is not included. The chapter continues with packed column distillation, and the use of the Fenske, Underwood, Gilliland method for (approximate) calculation of multicomponent distillation, for which three examples are given covering different aspects of this procedure. The chapter concludes by setting up the equations for a rigorous solution to multicomponent distillation based on both equilibrium stage and nonequilibrium models. Some results and discussion of nonequilibrium models are given. 34 homework problems are listed.

The last chapter in the book deals with "Liquid Extraction". Graphical solutions based on triangle diagrams are given for single-stage, multistage crosscurrent, and countercurrent extraction. Use of y-x for insoluble liquids and a Janecke diagram for countercurrent extraction with reflux is demonstrated (here, the terminology "Ponchon-Savarit" is mentioned). A section on equipment for liquid-liquid extraction concludes the chapter. 24 homework problems are given.

The index is very sparse (for example, the words "azeotrope" and "McCabe-Thiele" do not appear) with only about 350 entries. In addition to the electronic age typos mentioned above, there are others that usually are subtle and not confusing. However, at least one of the sets of learning objectives is from a previous chapter.

The book is very much a traditional treatment of a classic chemical engineering subject. If the topics that are needed for a given course are included in this text, I would expect educational experience to go smoothly for both student and instructor. I think that students will like this book, because the explanations are clear, the level of difficulty is appropriate, and the examples and included data give the book very much of a "handbook" flavor. Instructors will find that, overall, the topics are presented in a logical order and the discussion makes *sense;* there are many examples and lots of homework problems.

The limitation of the book is the omission of topics that are becoming increasingly important for chemical engineers. Membrane separations, chromatography and other adsorptive processes, ion exchange, electrophoresis, and, possibly, multistage batch distillation are topics that warrant some discussion in separations courses for chemical engineers.

Despite the advertising about inclusion of examples from computational software such as *Matlab* and *Mathematica* on the back cover and on the Wiley Web site, these words are not found in the index and I could not find such examples in the book. Further, the location of the advertised ftp site for Mathcad files is not given in the text. I found it by searching the Wiley Web site at ftp://ftp.wiley.com/public/SCLtech med/mass_transfer.

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