

Elementary Principles of Chemical Processes

3rd Edition

By Richard M. Felder and Ronald W. Rousseau

John Wiley & Sons, 605 Third Avenue, New York, NY 10158-0012; 675+ pages; \$111.95 (cloth); (2000)

Reviewed by

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The third edition of this classic introductory chemical engineering text is intended to compliment a first course in stoichiometry, material and energy balances, and introductory thermodynamics. As such, it is aimed at engineering and chemistry students who have completed their first year of general university education. Freshman physics and chemistry are valid prerequisites, although if the course is taught with the complimentary teaching modules, one could consider offering it earlier. The third edition follows the same format as the previous two editions, with a preliminary set of three chapters discussing the units and dimensioning of process variables and their associated calculations. This section is (in some curricula) omitted, due to its coverage in other courses, but it is a valuable asset since many student difficulties in balances occur due to sloppy "accounting."

The body of the text discusses material balances, first for non-reactive single-phase processes and then adding multiphase systems, recycling, and bypass. One of the strengths of the book is the ease with which the authors' introduce thermodynamics into the subject matter. Equations of state for non-ideal gases, compressibility, multicomponent equilibrium, and two-phase partitioning and solid-liquid-vapor phase diagrams are presented in a comprehensible manner that permits students to begin solving problems on the day of the lecture. This is something Felder has long advocated in his interactive teaching approaches, and the third edition certainly shows the value of the NSF's sponsoring of the concepts which brought it to fruition.

The text also integrates graphical presentations of correlations with computer-based programming challenges. The students will not realize until subsequent courses, to what extent they have been introduced to (and to a large extent mastered) elementary chemical and engineering thermodynamics. The problems at the end of the chapter do an excellent job of integrating the concepts presented, along with statistics, into the estimation of thermodynamic data.

Practical problems, related to a series of important unit operations including various separation methods such as absorption, adsorption, condensation, crystallization, distillation, and extraction are presented throughout the first eleven chapters. The authors' also discuss batch, semi-batch, and

continuous reactors operating under adiabatic and isothermal conditions, both at steady state and dynamically. Combustion is treated separately. Liquid-gas processes including evaporation-compression, humidification, dehumidification, and scrubbing are also integrated into material and energy balances. Overall, the new problems are challenging, yet doable.

The third section of the book discusses energy and energy balances. There is minimal overlap with the discussion of forms of energy typically presented in freshman physics. Energy balances on non-reactive processes challenge students to organize their solutions. The text pulls itself together in Chapter 9 when the enthalpy of reaction is used, and estimated, principally to permit the calculation of a reactor's energy loss, temperature, or pressure. The balances are also extended to complete processes. Discussions of alternative fuels, which may appear old-fashioned, is a take-home deliverable from this text, as are its extensive data base (tables, graphs, and CDs) that may convince sophomores they never have to set foot in an engineering library.

The text concludes with a chapter on computer-aided calculations, which many schools cover in a separate course (as they do the material on transient processes). But if Chapters 10 and 11 are omitted, Chapters 12 through 14 cannot be. The authors' offer three case studies (one in the area of materials and two in commodity chemistry) that need to be presented at the end of the two-semester sequence to convince students they can, indeed, design plants. It is a motivation which will drive many of them to integrate kinetics, reactor design, transport phenomena, and separations into their working knowledge and become chemical engineers. As the only chemical engineering course taught to chemists, in my experience, it provides an excellent sensitization to the challenges facing industrial organic and polymer chemists when they develop new (macro) molecules.

The text comes with a CD that includes an animated encyclopedia of chemical process equipment, the E-Z solve software for balances along with tutorials, and an index of learning styles. As fantastic as these are, the real value is that the physical property database demystifies the coupling between thermodynamics and engineering, which confuses so many students. With the database provided, carrying out material balances is no longer a cumbersome task akin to financial accounting, but is fun. Felder and Rousseau have made chemical engineering enjoyable. My students make significantly less calculation errors on their balances thanks to the third edition of this book, and they are motivated and listen better to the concepts their predecessors had ignored.

Overall, the authors' present a way for introductory students to respect complexity and understand the need for engineering approximations. Take the authors' advice to let the students enjoy problem-based learning—they will better understand themselves, their career, and their choices. The book is a service to our profession. □

cal work, take time to discuss work habits when necessary. For example, most graduate students have not learned how to rapidly sort articles so that only the most important are read thoroughly. The professor can also be a cheerleader when groups feel that they will never be able to finish their projects. When the members of a group are not getting along, part of the meeting time can be used to help the students start processing group interactions. Do not try to solve their interpersonal problems, however. Make the students do this work or at least muddle through it.

The bane of grading group work is freeloaders. Delegate the responsibility of lowering the grades of freeloaders to the students. My grade assigned to each project is the highest grade students in the group can receive for the project. I require the students in each group to assign what percentage of this grade (ranging from 0 to 100%) each group member should receive. I then average these percentages for each group member and calculate their project grades. This procedure reduces freeloading and drastically reduces complaints from other group members when freeloading occurs.

This project-based paradigm is very efficient for professors. During the project work I typically spend a total of four hours per week on the course, with most of that time focused on the students. During project work the students spend much more time working on the course than the professor does!

Grading reports takes time, but since the reports are better than in other classes it is easier. The students learn their topic in depth, they learn how-to-learn, and they actually pay attention to the feedback on their writing.

A note of caution is in order, however. Most professors and students are inexperienced with project-based teaching. Professors need a certain amount of chutzpah to relinquish the normal control of a lecture course. They also need to know the material better than they would for a lecture class since it is impossible to prepare for student questions. Note that this method is not "turning the students loose." Students actually receive increased guidance and support. Despite the support, the freedom and responsibility may overwhelm immature students. Students, particularly those with high grades, may rebel. Other faculty may be skeptical and probably will not be supportive if the course flounders. Because of these risks, a graduate- or senior-level elective course is a good place to experiment.

IMPROVEMENT AND GROWTH

Master teachers may be born, not made; but good, efficient teaching is a learned skill. Sign up for a teaching workshop. Study and try out new teaching methods. After each class, reflect on what worked and what didn't, and tailor your future actions accordingly. Take notes, with the aim of improving the course next time. Find someone in your department with whom you can discuss teaching on a

regular basis. Continual experimentation with teaching methods helps to prevent boredom and burnout, which can be major problems. Such experimentation can lead to teaching improvement and eventual recognition as a master teacher.

REFERENCES

1. Covey, S.R., *The Seven Habits of Highly Effective People*, Simon and Schuster, New York, NY (1989)
2. Lakein, A., *How to Get Control of Your Time and Your Life*, Signet Books, New York, NY (1973)
3. Wankat, P. C., "Effective, Efficient Teaching," Proceedings ASEE 1999 Annual Conference, CD ROM pdf file 000167, (1999)
4. Wankat, P.C. and F.S. Oreovicz, *Teaching Engineering*, McGraw-Hill, New York, NY (1993). [Out of print. Available free as pdf files at <<http://unitflops.ecn.purdue.edu/ChE/News/Book/>>
5. Boice, R., *The New Faculty Member*, Jossey-Bass, San Francisco, CA (1992)
6. Boice, R., *Advice for New Faculty Members: Nihil Nimus*, Allyn and Bacon, Boston, MA (2000)
7. Woods, D.R., *How to Gain the Most from Problem Based Learning*, D.R. Woods, Waterdown, Ontario, Canada, (1994). [Available from McMaster University Bookstore, 905-572-7160]
8. Wankat, P.C., "Learning Through Doing: A Course on Writing a Textbook Chapter," *Chem. Eng. Ed.*, **27**(4), 208 (1993) □

ChE book review

Multimedia Fluid Mechanics

by G.M. Homsy, *et al.*

Cambridge University Press (2000) \$19.95

Reviewed by

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The CD by Homsy, *et al.*, is a most welcome and timely educational tool for students (and instructors!) of introductory fluid mechanics. Fluid mechanics is a very visual discipline. To date, such visual accompaniment to the mathematical equations describing flow physics has either come from labs or from samplings of the fantastic movies put together in the 1960s. Whereas the material of those movies will never become outdated, the innovative multi-media approach adopted by Homsy, *et al.*, adds dimensions to the presentation that were simply not available forty years ago. This CD ROM is a true multi-media tool that has no paper counterpart. In other words, this is not a book typed on a CD—it is truly all that the box cover promises, and then some.

The approach is based on modules. Currently, there are three technical modules, with more promised. The current modules are dynamics, kinematics, and boundary layers. There is also a module on history, which should be studied by all students.

Continued on page 101.

“U-tube”) downstream of the micro-metering valve before and after each trial as an alternative to obtaining the amount of naphthalene extracted in the experiment. The mass of the extracted naphthalene would be a more significant portion of the total mass of the sample and apparatus being weighed. In this manner, more accurate results may be possible.

If multiple groups complete the lab during the semester, another enhancement to the laboratory experience could be to have the different groups use different solute materials. At the end of the semester, a comparison of the correlation constants from each group could be completed and this could be used to create a generalized correlation. Possible alternative solutes include biphenyl and benzoic acid. Should this approach be taken, it is important to remember that the value of A, the surface-to-volume ratio in Eq. (1), must be provided for each system investigated.

In summary, this laboratory experiment provides a valuable introduction to a modern unit operation in the chemical process industry while at the same time it encourages creative thinking in the synthesis of concepts from disparate areas of chemical engineering.

NOMENCLATURE

A	Surface area per unit volume of a packed bed (m^2/m^3)
a,b,c,d	Correlating equation parameters
C_1	Average concentration of naphthalene in exiting carbon dioxide (kg/m^3)
C_1^{sat}	Concentration of naphthalene in carbon dioxide at saturation (kg/m^3)
ΔC_{LM}	Log mean concentration driving force (kg/m^3)
D	Column diameter (m)
D_{AB}	Diffusivity (m^2/sec)
d	Particle diameter (m)
g	Acceleration due to gravity (m/sec^2)
k	Mass transfer coefficient (m/sec)
P	Pressure (bar)
P^{sat}	Vapor pressure of solute (bar)
R	Ideal gas constant ($\text{m}^3\text{bar}/\text{molK}$)
T	Temperature (K)
V	Molar volume of fluid phase (m^3/mol)
V^{sol}	Molar volume of solute (m^3/mol)
V^0	Empty column superficial velocity (m/sec)
z	Packed bed length (m)
ρ	Density (kg/m^3)
μ	Viscosity ($\text{kg}/\text{m sec}$)

Dimensionless Numbers

N_{Gr}	Grashof number ($d^3 g \rho \Delta \rho / \mu^2$)
N_{Re}	Reynolds number ($D V^0 \rho / \mu$)
N_{Sc}	Schmidt number ($\mu / D_{\text{AB}} \rho$)
N_{Sh}	Sherwood number ($k z / D_{\text{AB}}$)

REFERENCES

- Hannay, J.B., and J. Hogarth, “On the Solubility of Solids in

- Gases,” *Proc. Roy. Soc.*, **29**, 324, London (1879)
- McHugh, M.A., and V.J. Krukonis, *Supercritical Fluid Extraction, Principles, and Practice*, 2nd ed., Butterworth, Stoneham, MA (1994)
- Eckert, C.A., J.A. Van Alsten, and T. Stoicos, “Supercritical Fluid Processing,” *Environ. Sci. Tech.*, **20**, 319 (1986)
- Maddocks, R.R., J. Gibson, and D.F. Williams, “Supercritical Extraction of Coal,” *Chem. Eng. Prog.*, **49** (1979)
- McHugh, M.A., and M.E. Paulaitis, “Solid Solubilities of Naphthalene and Biphenyl in Supercritical Carbon Dioxide,” *J. Chem. Eng. Data*, **25**, 326 (1980)
- Gabbard, R.G., “The Development of a Senior Unit Operations Laboratory on the Supercritical Extraction of Solid Naphthalene with Supercritical Carbon Dioxide,” M.S. Thesis, New Jersey Institute of Technology (1993)
- Debenedetti, P.G., and R.C. Reid, “Diffusion and Mass Transfer in Supercritical Fluids,” *AIChE J.*, **32**, 2034 (1986)
- Lee, C.H., and G.D. Holder, “The Use of Supercritical Fluid Chromatography for Obtaining Mass Transfer Coefficients in Fluid-Solid Systems at Supercritical Conditions,” *Ind. Eng. Chem. Res.*, **34**, 906 (1995)
- Jossi, J.A., L.I. Stiel, and G. Thodos, “The Viscosity of Pure Substances in the Dense Gaseous and Liquid Phases,” *AIChE J.*, **8**, 59 (1962)
- Funazukuri, Y., Y. Ishiwata, and N. Wakao, “Predictive Correlation for Binary Diffusion Coefficients in Dense Carbon Dioxide,” *AIChE J.*, **38**, 1761 (1992) □

Multimedia Fluid Mechanics

Continued from page 95.

The CD is neither a book nor a collection of movie clips. It is truly a seamlessly integrated multi-media tool. The user can read some brief text describing the phenomenon, can look at the equations and see the meaning of each term, and also look at some movie clips that will drive the point home. Most importantly, there are a number of very simple, but cleverly designed, interactive experiments where the user can take data off of a running movie clip and process the automatically tabulated data in order to investigate the dimensional relationships and gain valuable insights. These interactive experiments constitute very nice classroom demonstrations to supplement lectures. An equation feature that is used cleverly is a roll-over feature where as the mouse pointer is dragged over each term of the equation, the term is magnified and highlighted, and its meaning pops up in a small text box.

I cannot overemphasize how well this CD is done. The selection of the topics, the level of coverage, and the actual presentation are all superb. There are many hyperlinks throughout the CD; however, unlike some other CDs where the user can hyperlink his/her way into a digital purgatory, on this CD one can always return to the page of interest using the small navigation map at the top of the page.

Congratulations to Professor Homsy and his colleagues for undertaking the much-needed task of creating a new tool for aiding students of fluid mechanics. Also, congratulations for holding the line on the price, which is extremely reasonable in an environment of skyrocketing textbook prices. □

simultaneous achievement of three conditions: homogeneity of pressures (mechanical equilibrium), homogeneity of temperature (thermal equilibrium), and homogeneity in chemical potential (diffusive equilibrium); i.e., *only* if all three conditions ($P^A = P^B$, $T^A = T^B$, and $\mu^A = \mu^B$) are simultaneously met can we affirm that the system will not change in time if left alone.

Solution #1, as Missen and Smith note, pertains to the achievement of mechanical equilibria, but as is also noted in the original article, leaves a temperature gradient among tanks A and B. Given enough time, mass diffusion must take place, transferring *energy* from tank B to tank A. So, even though tank B has adiabatic walls and thus no heat transfer to the surroundings, it does transfer energy due to a temperature difference.

In hindsight, the phrase “Given enough time, this temperature gradient will produce a transfer between the tanks” should read, “Given enough time, this temperature gradient will produce a mass transfer and consequent energy transfer between the tanks” in order to be unambiguous.

It is clear, however, that there are not two solutions to the problem, even if the catchy title implies so. Only one solu-

tion is possible. Any argument attempting to set solution #1 as the correct one must first disprove solution #2—an impossible task.

Many students and teachers (and Spicer’s note is a clear example) apply the textbook equations directly to a problem without further thought on the problem. It is in this sense that I totally agree with the second point noted by Missen and Smith. I believe that one should teach the general energy balance, and for each particular case simplify it accordingly.

The point of the original class problem is that if one starts directly with Eq. (2), one may elude some of the assumptions behind its derivation. One should always start with a generalized equation such as Eq. (7)* and integrate it according to the given problem. Categorizing systems as steady state, uniform flow, etc., and stating formal equations in each case only entices the student to learn a myriad of equations, making things more difficult and prone to errors.

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* Equation (7) is identical (with the exception of the arbitrary sign given to the work) to Eq. (A) of Missen and Smith, not to Eq. (E) as stated in their comment.

ChE book review

Advanced Transport Phenomena

by John C. Slattery

Published by Cambridge University Press, The Edinburgh Building, Cambridge, UK; 734 pages; available in paperback and hardcover

Reviewed by

David C. Venerus

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Advanced Transport Phenomena is a new textbook written by Professor J.C. Slattery that represents a revision of an earlier text by the same author: *Momentum, Energy and Mass Transfer in Continua* (1981). Transport phenomena is a fascinating and interdisciplinary subject that is covered by at least one required course in all graduate chemical engineering programs and remains an active area of research. Like its predecessor, the new book is intended for graduate students in engineering.

The text is organized into three topics according to the main subjects of transport phenomena: momentum, energy, and mass transfer. In addition, there are two shorter topics that are covered; kinematics (coming before the three main topics) and tensor analysis (an appendix). Each of the three main topics is divided into three sub-topics that can roughly

be described as the formulation, application, and reduction of transport balance equations. This matrix style of organization, where the columns are the main topics (momentum, heat, and mass) of transport phenomena and the rows provide the components and applications for each topic, is similar to that used in the classic text *Transport Phenomena* by Bird, Stewart, and Lightfoot (BSL), and allows the instructor/reader the flexibility to cover the topics by column or by row.

The style and teaching philosophy of the author are revealed in Chapter 1 (kinematics) where concepts such as motion, velocity, and phase interfaces are introduced. Various transport theorems are developed and used to derive the differential mass balance, or continuity equation, and the jump mass balance from the mass conservation postulate. Hence, the approach taken here and throughout the book is to start from general postulates about the physical world and to convert these postulates into useful conservation equations using formal mathematical tools.

The sub-topic structure is itself instructional in that the reader is forced to recognize the similarities (and differences) between momentum, heat, and mass transfer. In Chapters 2, 5, and 8 (Foundations for...), differential forms of the conservation equations and their corresponding two-dimensional forms (jump balances) are derived simultaneously.

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This is followed by rather lengthy developments on the behavior of materials where the most widely used (classical) constitutive equations are eventually presented. In Chapters 3, 6, and 9 (Differential Balances in...), various transport problems are formulated using the conservation and constitutive equations derived in preceding chapters. These problems, which range in complexity from one-dimensional, steady-state problems to two-dimensional problems that include boundary-layer theory, are solved using both analytical and numerical techniques. Chapters 4, 7, and 10 (Integral Averaging in...) are devoted to deriving reduced forms of the differential balance equations: time-averaged (turbulent flows), area-averaged, local volume-averaged (pseudo continuous media), and global volume-averaged (macroscopic balances).

Appendix A provides a comprehensive review of tensor analysis and includes operations in both rectangular Cartesian and curvilinear coordinate systems.

Scattered throughout each chapter are several worked examples, and each chapter ends with a series of exercises (for which a solution manual is available). At the end of each "Foundations of..." chapter, there is a summary subsection where the reader will find tables with the conservation equations expressed in rectangular Cartesian, cylindrical, and spherical coordinate systems.

There is no question that *Advanced Transport Phenomena* is a comprehensive and carefully prepared textbook. The use of material volumes and transport theorems (rather than stationary differential volumes, as is BSL) to derive differential conservation equations is appropriate for graduate-level courses. Significant attention is given to the behavior of materials and to the entropy inequality and its use in the formulation of constitutive equations.

Another positive aspect of this book is the utilization of jump balances to derive boundary conditions. Jump balances are rarely covered in modern texts on transport phenomena, but are invaluable in situations involving free and/or moving boundary problems. I particularly like the tables in Chapter 2 where the jump mass and jump linear momentum balances are given for several special surfaces in the three main coordinate systems.

Where the optimal balance is between being mathematically rigorous and comprehensive while also developing

physical insight on transport problems is, of course, a matter of preference. Many readers of this book might find that there is too much emphasis on the first two at the expense of the third. As I read through certain portions of the book, I sometimes found myself leafing through page after page of derivation to find the punch line. (From my own rough estimate, there are on average a little more than seven equations per page, or, in the 700-page book, a total of about 5000 equations!) For example, in section 5.3, roughly ten pages are used to transform some general postulates about the thermal behavior of materials into useful results (*i.e.*, viscosity and thermal conductivity are positive, Fourier's law, internal energy can be expressed in terms of density, pressure, temperature, and a heat capacity). Unfortunately, discussion about the physical implications for the different constitutive assumptions used in the development is scant.

Another comment is that the book is almost comprehensive to a fault. For example, readers may find the results from the integral averaging chapters of marginal value, either because the subject is too complex to be developed at an advanced level (*e.g.*, turbulence and pseudo continuous media), or because it was too simple and therefore inappropriate for a graduate-level text (*e.g.*, macroscopic balances). Also, it is unlikely that one will find a situation that calls for the macroscopic moment-of-momentum balance or the jump entropy inequality. These portions of the book could have been better used to provide more physical insight or to analyze moving boundary problems, which are so prevalent in materials science and engineering. Having said that, educators and researchers in this field will be glad to have a single book where the equations needed to handle such a wide variety of transport problems can be found.

Advanced Transport Phenomena is a comprehensive textbook that provides systematic coverage of a challenging subject. It can be used as a primary text for a first-year graduate course on transport phenomena; students with prior exposure to the subject at the level provided by BSL will have a sufficient background. It could also serve as a solid reference book for more advanced graduate courses on fluid mechanics or on heat and mass transfer. My overall impression of the book is positive; I recommend it to those with an interest in teaching graduate-level transport phenomena or to those interested in learning advanced topics in this important and fascinating field. □