$$dU = TdS - PdV + \sum_i \mu_i dN_i \qquad (37)$$

The above definitions of T and P are no different to those we have used previously. We may define the functions A, H, and G as we have done before. Thus

$$A = U - TS = A^{TV[N_j]}$$

and H and G are defined in an analogous fashion.

There are also many new functions we could define with canonical variables involving one or more of our new variables $[N_j]$. For instance

$$B = U - \mu_1 N_1 = B^{SV\mu_1[N_{j\neq 1}]} \qquad (38)$$

but these in general do not turn out to be useful functions, so we shall not explore this avenue further.

We may also obtain, as we did above, a set of Maxwell relations. For example, from the second derivatives of U, we may obtain

$$T^{SV'[N_j]} = -P^{S'V[N_j]} \qquad (39)$$

while from A we may obtain

$$S^{TV'[N_j]} = P^{T'V[N_j]} \qquad (40)$$

Many other relationships are of course possible. For example

$$\mu_j^{TPN'_j[N_{k\neq j}]} = \mu_i^{TPN'_i[N_{k\neq i}]} \qquad (41)$$

It perhaps needs to be stressed again at this point that all the above development is purely mathematical. All the relations we have developed follow from the properties of functions and their derivatives and from our (arbitrary) definition of the symbols P and T in terms of the derivatives of U^{SV}. We have not yet done any "thermodynamics"!

The development that may be referred to as "thermo" (including the identification of our symbols T and P with their usual meaning) will form the subject of Part 2 of this paper.

We may also note that in this approach the mathematics we use is entirely consistent with that which a student has learned in the standard mathematics course. In particular, we have no need for any special kinds of derivatives. We have found in our teaching that students readily assimilate this material and do not appear to have the same problems of understanding that the authors did when they were undergraduates.

REFERENCES

1. Harris, W.F., *ChemSA*, **7**(12), 259 (1981)
2. Harris, W.F., *ChemSA*, **8**(7), 82 (1982)
3. Callen, H.B., *Thermodynamics*, John Wiley & Sons, New York, NY (1960) ❐

ChE book review

A GUIDE TO CHEMICAL ENGINEERING PROCESS DESIGN AND ECONOMICS

by Gael D. Ulrich
John Wiley & Sons; 472 pages, $33.95 (1984)

Reviewed by
Andrew N. Hrymak
McMaster University

This book is intended as a reference text for a course using case studies such as those from the AIChE design competition. Topics covered in the book fall into three main categories: process design, economics, and technical report writing. Extensive references to well-known chemical engineering texts and handbooks are found throughout the book.

The first section is entitled "Process Design." The chapters within this half of the book cover the design process, process conception, flowsheets, and the specification and design of individual pieces of equipment. In Chapter 2, the reader is introduced to the importance of understanding the process and obtaining typical flowsheets from the literature and Chapter 3 summarizes flowsheet preparation and common symbols.

Chapter 4 is a lengthy chapter devoted to the specification and design of individual pieces of process equipment. Separate sections cover different classes of units (such as heat exchangers, pumps, reactors, *etc.*). Each section gives a brief overview of

Continued on page 95.

ber of dimensionless depths, z/L. A rapid decrease in the chlorine concentration is interpreted in terms of its fast consumption via chemical reaction relative to its diffusion in the liquid phase. Agreement between the analytical solution of Eq. (8) and the numerical solution of Eq. (6) as seen in Figure 3 justifies the assumption of constant velocity in Eq. (8). The mass transfer enhancement factor value of 1.98 is indicative of about double the chlorine removal rate via its absorption without chemical reaction. The model predictions suggest that the continuously flowing liquid films can, indeed, be used for purification of gas mixtures, *e.g.,* chlorine/nitrogen or air mixture, by absorption of trace species, *e.g.,* chlorine, with chemical reaction in the liquid phase.

REFERENCES

1. Bird, R.B., W.E. Stewart, and E.N. Lightfoot, *Transport Phenomena,* John Wiley and Sons, New York, pp. 537-539 (1960)
2. Rosner, D.E., *Transport Processes in Chemically Reacting Flow Systems,* Butterworths, Boston, MA., p. 393 (1986)
3. Smith, J.M., and H.C. Van Ness, *Introduction to Chemical Engineering Thermodynamics,* McGraw-Hill Book Co., New York, NY, p 332, 346 (1987)
4. Reid, R.C., J.M. Prausnitz, and T.K. Sherwood, *The Properties of Gases and Liquids,* McGraw-Hill Book Co., New York, NY, p. 361 (1977)
5. Spiegel, M.R., *Advanced Mathematics,* McGraw-Hill Book Co., New York, NY, pp. 277, 100, 73 (1977)
6. Oberhettinger, F., and L. Badii, *Tables of Laplace Transforms,* Springer-Verlag, New York, NY, p. 264 (1973)
7. Abramowitz, M., and I.A. Stegun (editors), *Handbook of Mathematical Functions,* (9th printing), Dover Publications, Inc., New York, NY, p 299 (1970) ❐

REVIEW: Process Design

Continued from page 79.

the major types of equipment in the class, the basic operating principle, literature references, and sketches or photographs of the units. Short-cut sizing techniques and rules-of-thumb are used throughout the chapter for rough sizing. The major feature of the chapter is a set of tables which provide criteria for the preliminary specification of units within each equipment class. The selection tables are organized by principle of operation, applicable capacity range, important data to that class of equipment (*i.e.,* particle size for crushing equipment), material compatibility, type of service, and any other criteria useful for differentiating alternatives within the class of equipment. Qualitative ranking of the units is provided when numerical comparisons are not appropriate for comparing equipment, such as past experience in the suitability of the unit for a particular problem application. I tried to use the tables by selecting some units that I was particularly familiar with and found that they (and the text) provided enough basic information to describe the unit and give a size range. There is enough information to select a unit given the feed characteristics, but not enough information to do any analysis of the operation of the unit or detailed sizing.

The second section of the book (approximately one hundred and fifty pages) covers "Economic Analysis." Chapters cover capital and manufacturing cost estimation, economic optimization, and cash-flow analysis. The cost estimation techniques presented are adequate for a preliminary estimate. Figures provide capital cost estimates for different types of units, but there is no information about the error or spread of data used to create the figures. The chapter on cash-flow analysis (time value of money) is brief, and the coverage on the treatment of alternative investments could use more examples and discussion.

The final, brief, section is a single chapter on "Technical Reporting." There are many anecdotes to encourage the student to write effectively. It would have been useful to provide example outlines for different types of engineering design reports to give the student an idea of what information is expected, depending on the type of study being done.

After I finished reading the book, there were a number of things that troubled me. The *design process* is not emphasized as an iterative process that requires preliminary sizing and costing and then more detailed study and operations analysis (which may force changes in the original process concept). Little reference is made to modern computer packages that can do both the short-cut and the rigorous mass and energy balances (and sometimes the economics), and which allow the student to do a second pass at the design. The overall plant design is a set of chemical operations for which one must make decisions about unit alternatives as well as the process configuration itself. Process units interact through recycles so that design decisions in one unit can affect the operation, size, and economics of the rest of the plant. Some material and detailed examples on process configuration alternatives (process synthesis) would be useful for the student to see that different process concepts are possible.

If the instructor has a design course that is based on a well-defined case study, then the book provides reference material that would be useful for preliminary unit design and economic analysis. ❐