SEPARATIONS
What to Teach Undergraduates

P. C. WANKAT, R. P. HESKETH,[1]
K. H. SCHULZ,[2] C. S. SLATER[3]
Purdue University
West Lafayette, IN 47907

Separations (also known as mass transfer or unit operations) have always been an important area in chemical engineering, but recently separations have become a critical concern.[1-4] This concern arises because separations are typically between 50% and 90% of the plant cost and because the subject is so important in "hot" areas such as biotechnology and the environment.

A workshop at the ASEE Chemical Engineering Division Summer School in Bozeman, Montana, in August of 1992, wrestled with the problem of what separations should be taught to undergraduate chemical engineers. The workshop consisted of an overview of separations, a short presentation on educational ideas and educational philosophy, and small work groups discussing their curricula and the question of what to teach.

OVERVIEW OF SEPARATIONS

The general consensus of the workshop participants was that undergraduate students should be introduced to a broad overview of separations. One way to present this overview in a concise format is to use the classification shown in Figure 1.[5] Some of the working groups found this scheme to be useful for organizing their thoughts—the scheme should also be useful to undergraduates, particularly global thinkers. If this or a similar classification scheme is shown, then each of the separations categories must be discussed. Several concrete examples from each separation category should be presented to the students. Within the category of equilibrium separation processes, the concept of a separating agent is useful.

Two other concepts which are useful for an overview of separations are the relationship between feed concentration and selling price[6,7] and the wide range of production rates for different separations (see Figure 2). The Sherwood plots[6,7] can be used to make the point that more concentrated feeds are easier to separate. Also, the point can be made that not all raw material sources are equal. Product rates for separations vary enormously, as shown in Figure 2.[2] The type of separation used often depends on product rates. This can easily be illustrated for oxygen production at different product rates. For very small units membrane permeation and pressure swing adsorption compete, for medium-size units pressure and vacuum swing adsorption units seem to be favored, and for very large units cryogenic distillation is least expensive.

Our experience is that these concepts are easily understood by undergraduates. The concepts help the students obtain a perspective on separations and to understand the similarities and differences between separations. It is useful to present Figure 1 both at the very beginning of the semester to illustrate the course structure and at the very end to help review the material. Figure 1 also helps the students realize that there are many other separations in addition to those they studied. If one goal is to produce innovative

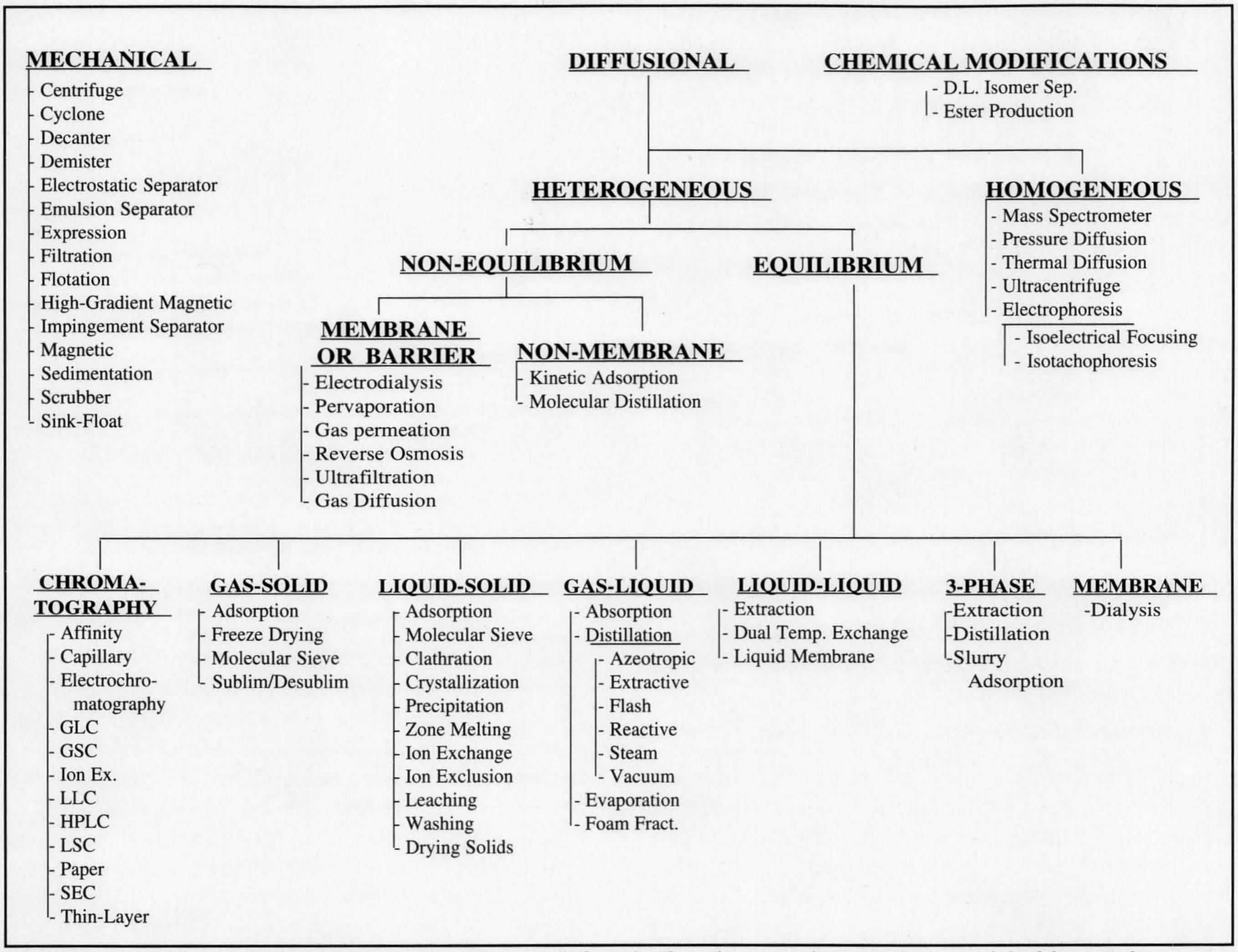
[1] University of Tulsa, Tulsa, OK 74104-3189
[2] University of North Dakota, Grand Forks, ND 58202
[3] Manhattan College, Riverdale, NY 10471

__Phil Wankat__ received his BSChE from Purdue and his PhD from Princeton and is currently a professor of chemical engineering at Purdue University. He is interested in teaching and counseling, has won several teaching awards at Purdue, and is Head of Freshman Engineering. His research interests are in the area of separation processes, with particular emphasis on cyclic separations, adsorption, preparative chromatography, simultaneous fermentation, and separation.

__Robert P. Hesketh__ is an assistant professor at the University of Tulsa. He received his BS (1982) at the University of Illinois Urbana, and his PhD (1987) from the University of Delaware. He teaches undergraduate mass transfer and chemical reactor design, and graduate reaction kinetics, multiphase reactor design, and combustion. His research interests include incineration, combustion, and multiphase flows.

__Kirk H. Schulz__ is an assistant professor at the University of North Dakota. He received his BSChE and PhD in chemical engineering from Virginia Polytechnic Institute and State University in 1986 and 1991, respectively. His research interests include surface science and catalysis, with teaching interests in mass transfer, chemical kinetics, and physical chemistry laboratories.

__C. Stewart Slater__ is a professor of chemical engineering at Manhattan College. He received his PhD, MPh, MS, and BS degrees in chemical engineering from Rutgers University. His research and teaching interests are in separation and purification technology, membrane processes, and biotechnology.



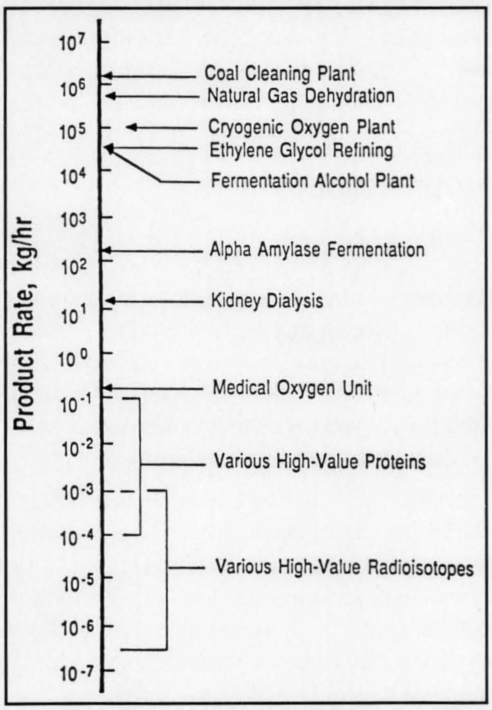


Figure 1 (Above). *Classification of Separations. Modified from Reference 5.* Reprinted with permission from P.C. Wankat, *Rate-Controlled Separations,* Elsevier, Barking, England. Copyright 1990, Elsevier Science Publishers Ltd.

Figure 2 (Left). *Product rates for various Separation Processes.*[2] Reproduced by permission of the American Institute of Chemical Engineering from G.E. Keller, III, *AIChE Monograph Series,* 83 (17), 1987. Copyright 1987, AIChE. All rights reserved.

engineers, then Figure 1 coupled with Figure 3[2] are useful. Figure 3 is also useful in design classes to help explain the strong preference of many companies for well-known technology. The Sherwood-type plot[6,7] can be included in the course when the economics of separations are covered, or as part of the overview when Figure 1 is discussed. Figure 2 can also be part of the course overview, or it can be profitably employed when discussing the use of competing methods for the same separation problem.

EDUCATIONAL IDEAS AND PHILOSOPHY

The choices of what to teach and how to teach it are heavily influenced both by which educational methods work and by our philosophy of chemical engineering education. These topics were briefly covered in the workshop to give all of the working groups a common basis.

Inductive reasoning starts with specific cases and is followed by the development of general rules, while *deductive* reasoning starts with a general theory and derives specifics from the general theory. Both methods are useful and are powerful reasoning methods; but inductive reasoning is the natural mode for learning completely new areas. Thus, when the students are exposed to separations for the first time, the use of inductive reasoning will be more effective. In elective and graduate student courses where the students are seeing some of the material for a second time, deductive reasoning may be a more efficient way to teach.

Four concepts of educational philosophy were presented and discussed at the workshop. The first three of them were extracted from Hougen's principles:[8]

1. *The undergraduate program should be practical and conservative, whereas the graduate program should be imaginative and exploratory.*
2. *There should be a smooth flow of information from graduate research to graduate teaching to undergraduate teaching.*
3. *If you can't find relevant problems to give the student, then you shouldn't be teaching the material to students.*

The fourth statement of educational philosophy was added by the lecturer, Phil Wankat:

4. *Different departments should do different things.*

In the discussion following the presentation there was general agreement with these four statements of educational philosophy. The practical result of the first and third concepts is that only separations currently used in industry were included in the proposed undergraduate courses. The application of the fourth concept led to a lack of consensus on what to teach.

WORKSHOP GROUPS

Five working groups, with six or seven professors in each group, began the workshop portion by introducing themselves and discussing their current course structure in separations. Separations courses included courses with titles such as Separations, Mass Transfer, or Unit Operations, among others. In addition, the separations parts of laboratory and design classes were included in the discussion. Each group developed an undergraduate curriculum in separations subject to the constraint of no increase in the credit hours. A reporter recorded the group's comments, made a presentation to the large group, and if desired became a coauthor of this paper.

One of the functions of the working groups was to share information about the wide variety of coverage on separations topics, both in the U.S. and the Canadian schools. Schools reported from one to four lecture-type courses covering separations topics. There appeared to be approximately an equal distribution between stand-alone separations courses and mass transfer courses with a major separations compo-

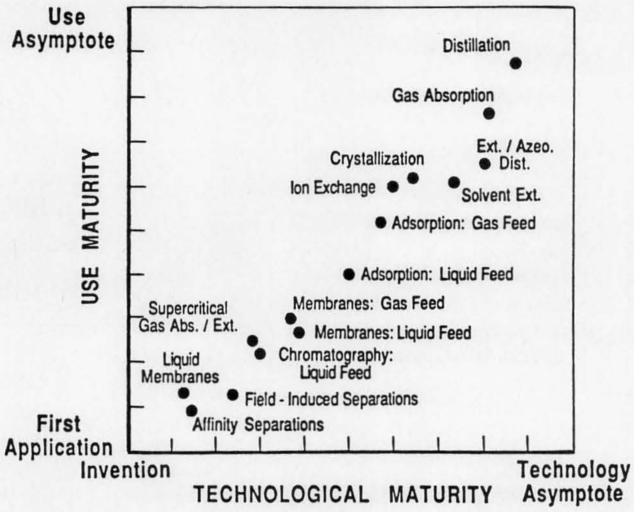


Figure 3. *Technological and Use Maturities of Separation Processes.*[2] Reproduced by permission of the American Institute of Chemical Engineers from G.E. Keller, III, *AIChE Monograph Series,* 83 (17), 1987. Copyright 1987, AIChE.

nent. In addition, all schools apparently include separations in laboratory and/or design courses.

At a few schools a significant portion of separations material was included in the capstone design course. Textbooks mentioned included: Bennett and Myers; Foust, *et al.;* Geankoplis; Henley and Seader; Hines and Maddox; King; McCabe, *et al.;* Skelland; Treybal; Wankat; and notes by Rousseau and by Tiller. This list of texts is similar to the bibliography in the latest AIChE mass-transfer survey.[9] Most schools supplement the textbooks with computer programs, often in design classes. Computer programs mentioned included Aspen, Aspen Plus, Flowtran, HYSIM, and various spreadsheets for doing McCabe-Thiele calculations. The working groups discussions showed a healthy diversity in both the material presented and the method of presentation.

WORKING GROUP RESULTS

None of the groups reached a consensus on what should be taught (except that all groups agreed that there was too much material to teach in the available time). This lack of consensus apparently occurred because of the large variety of offerings in separations and because everyone was explicitly encouraged to retain diversity. Despite the lack of an overall consensus, however, there were areas with substantial agreement—as well as an interesting split of opinions.

There was a general opinion that newer separations are under represented in the current curriculum. These processes include membrane separations (reverse osmosis, ultrafiltration, gas permeation, and pervaporation), adsorption including pressure swing adsorption, and chromatography. Since hybrid applications coupling two or more types of separations are becoming increasingly important in industry, students should be made aware of these applications—perhaps in a design course.

In addition to the underrepresented new separations, a number of important existing mechanical separations (see Figure 1) involving particulates have almost disappeared from the curriculum at many, but not all, schools. Since separation operations with particulates are extremely important industrially, some way needs to be found to either retain or reinstall them into an already crowded curriculum.

One of the chemical engineering laboratory courses was proposed as a convenient place to cover those separations which don't conveniently fit into existing courses. Examples include mechanical separations such as filtration, centrifugation, or flotation. Many schools already have these experiments in their laboratories, and they should certainly be retained and updated. Newer separations such as chromatography and membrane separations can easily be included in laboratory courses.

These topics were discussed in considerably more detail in other sessions at the summer school. One problem with using laboratory experiments is that at many schools *students* choose laboratory experiments and thus many of them will graduate without having done particular experiments. But the chance of exposure to a particular separation method was thought to be better than *no chance* of exposure. The lack of formal instruction on a given laboratory project was not thought to be a major problem since it forces the students to learn new material on their own.

Although there were a few strong dissenters, most participants felt their current curriculum was too heavy in distillation. At the same time, there was an intriguing 50/50 split among participants as to whether or not to retain the use of Ponchon-Savarit diagrams in distillation. Paradoxically, many professors wanted less coverage of distillation, but wanted to retain use of Ponchon-Savarit diagrams. It was thought that some room might be made in the curriculum by using computer-aided instruction programs for helping the students to visualize McCabe-Thiele and Ponchon-Savarit diagrams[10] and for doing "what-if?" calculations. This method might increase the rate at which the students learned this material. Of course, there would be a strong temptation to use the same amount of time and have the students learn the material more thoroughly. Since writing educational software is extremely time-consuming, this approach is efficient if, and only if, the programs can be widely shared. Some participants also felt strongly that their schools had too much coverage of liquid-liquid extraction.

As an illustration, the coverage at the authors' four schools is shown in Table 1. The order of topics in the table is not necessarily the order of presentation in the course. One can analyze the four required courses (not including Req'd. 2) in Table 1 for the lowest common denominator of course topics that is acceptable. The results are: Introduction (1), VLE (1), Flash distillation (1), McCabe-Thiele (8), Batch distillation (1), Short-cut distillation (1), Multicomponent distillation plus computer (5), Absorption/stripping (3), Extraction (3), Packed design (1), and Examinations (3). Thus, 28 of the 46 class periods (or 61%) are common to all four courses. The remaining 39% could be up to the discretion of the instructor. Obviously, this allows significant opportunity to teach different material.

TABLE 1
Course Outlines at Authors' Schools

	Class Meetings					
	Manhattan		*N. Dakota*	*Purdue*		*Tulsa*
Topic	*Req'd 1 (3 cr)*	*Req'd 2 (3 cr)*	*Req'd (3 cr)*	*Req'd (3 cr)*	*Elect (3 cr)*	*Req'd (4 cr)*
Introduction	1	1	1	1	1	1
Costs & Types of Separations	-	1	2	1	-	-
VLE	2	-	3	1	-	1
Flash Distillation	3	-	3	2	-	1
Distillation: McCabe-Thiele	8	-	12	9	-	12
Batch Distillation	1	-	3	2	-	2
Short-Cut Distillation Design	2	-	3	2	-	2
Computer Methods	2	-	3	1	-	-
Multi-Component Distillation	5	-	3	7	-	5
Adsorption/Stripping	4	-	3	3	-	5
Extraction	-	7	3	5	-	4
Leaching	-	2	-	-	-	-
Washing	-	2	-	1	-	-
Staged Column Design	4	-	-	2	-	-
Packed Column Design	3	-	3	1	-	1
Humidification	-	-	-	-	-	3
Adsorption	-	11	-	-	14	-
Chromatography	-	3	-	-	6	-
Electrophoresis	-	-	-	-	4	-
Ion Exchange	-	2	-	-	4	-
Membranes	-	11	-	-	9	3
Selection and Sequencing	-	-	-	1	1	-
Diffusion	3	-	-	-	-	8
Interfacial Mass Transfer	3	-	-	-	3	6
Exams (includes final)	5	6	4	7	4	3
TOTAL	46	46	46	46	46	57
Textbook	Treybal 1980	Wankat 1988&1990	Wankat 1988	Wankat 1988	Wankat 1990	Henley/Seader 1981 Treybal 1980

An elective course in bioseparations, particulate separation, or rate separations was considered to be a good method for allowing students to study additional separations without clogging the curriculum. These electives can be dual-level courses and might allow some faculty to teach in the area of their research. Unfortunately, when the details of an elective course were looked at there was considerable disagreement on the depth versus the breadth of the course. The compromise of covering a few topics in depth while other topics are only surveyed might be acceptable; but there was a strong feeling that the course had to be integrated (perhaps using Figures 1 to 3) and not be a series of unconnected topics. The coverage in an elective and a required advanced course at the authors' schools is shown in Table l.

SUMMARY

Like many other areas of chemical engineering, knowledge and application of new separation technologies are expanding at a rapid rate. The problem of how to introduce new separations into the curriculum is exacerbated by the neglect of particulate separations. Modest adjustments in current courses can probably be made by reducing the coverage of distillation and by adding new or neglected separations to the current course and in design and laboratory courses. One or more elective courses in separations are also highly desirable.

ACKNOWLEDGMENT

The authors thank all of the workshop attendees for their enthusiastic participation during the workshop. In particular, comments by recorders Alan Foss and Bonnie Tyler were helpful in writing this paper. We also thank the industrial supporters and the National Science Foundation for making the Summer School possible.

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ChE ***book review***

CHEMICAL OSCILLATIONS AND INSTABILITIES: Non-Linear Chemical Kinetics

by Peter Gray and Stephen K. Scott

Oxford Science Publication, Clarendon Press, Oxford; 453 pgs. $98.00 (1990)

Reviewed by

Massimo Morbidelli

Politecnico di Milano

Arvind Varma

University of Notre Dame

Following an overview introductory chapter, this book is divided into two parts which cover a total of fifteen chapters. The first part is the broader one and is titled "The Techniques," while the second part, "Experiments," consists of only two chapters.

In the first part, the backbone kinetic scheme is the so-called Autocatalator, whose complete version consists of the following reactions: P→A; A→B; A+2B→3B; B→C. It is