EXPERIENCE WITH A PROCESS SIMULATOR IN A SENIOR PROCESS CONTROL LABORATORY

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When we developed the senior process control laboratory at Lamar University, we acquired and installed a process simulator with full-fledged control and instrumentation. The process control laboratory has been a special-topic course in the undergraduate chemical engineering curriculum since the spring of 1992, and future plans call for a regular lab course to be taught along with it. A brief review of the development of the laboratory is the subject of this paper.

The process control laboratory was originally combined with the unit operations laboratory and included three analog units for level, flow, and temperature control in which the students were exposed to the tuning of 3-mode PID controllers by the Ziegler-Nichols method. These control units were designed and installed by Scallon Control, Inc., and the hardware was donated by Fisher Controls Company.

The need for developing computer-assisted labs became clear during the late 1980s.[1] As a first step, we developed a microcomputer-based pH control experiment in which the pH (process variable) of a given sample of water is controlled by adaptive control actions (variable gain). The process control laboratory currently also includes a PID tutorial program[2] and a video session for control valve selection and sizing.[3]

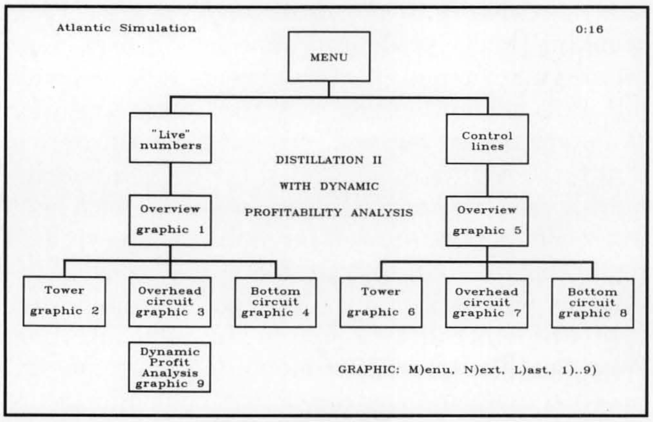

Figure 1. Main Menu

PROCESS SIMULATOR

Industry needs engineering graduates who have a good understanding of plant practices in addition to their command of engineering fundamentals. Process simulators help students gain those insights by giving them hands-on experience with plant-wide process control. The Atlantic simulator was chosen primarily because it is PC based and we wanted to be able to use existing personal computers as

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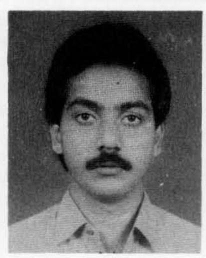

Jack R. Hopper *is Professor and Chairman of the Chemical Engineering Department at Lamar University. He has had over thirty years of industrial and teaching experience, holds four US patents, and has over fifty publications in a variety of fields. Current areas of interest are waste management and minimization.*

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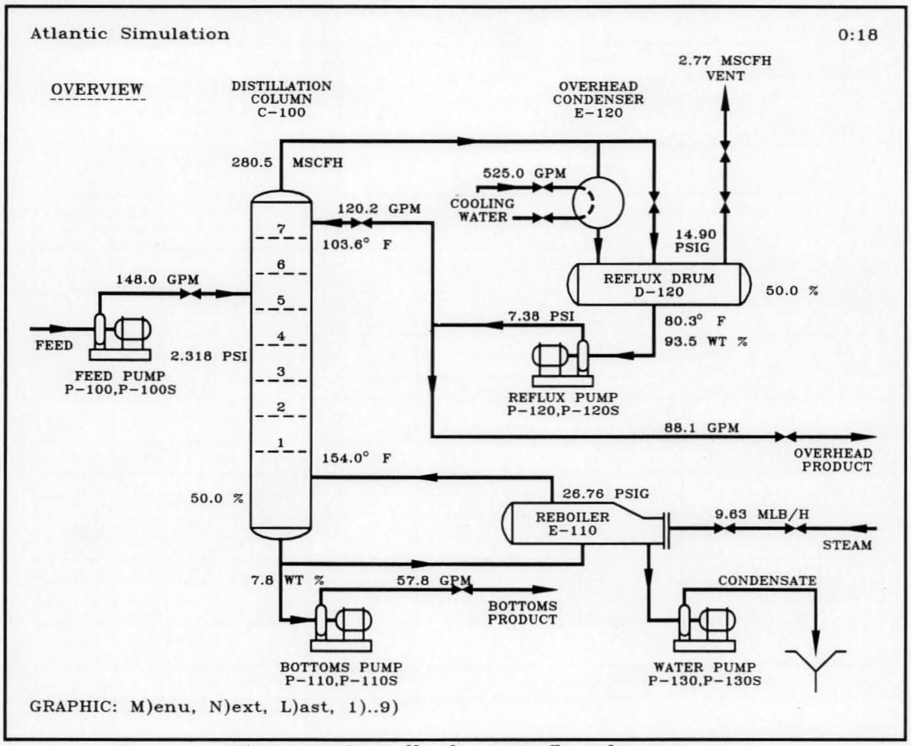

Figure 2. *Overall schematic flow diagram*

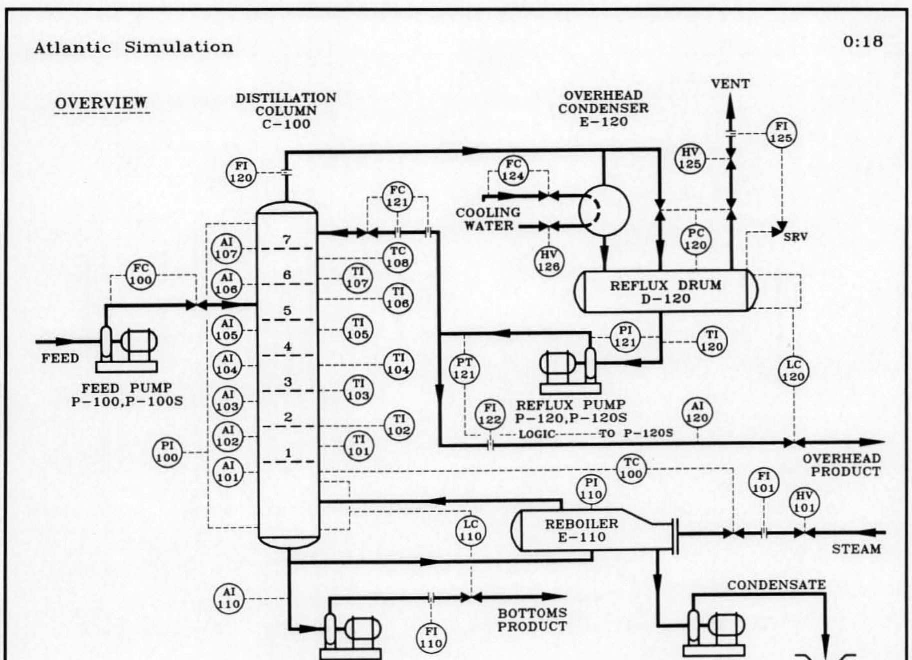

Figure 3. *Process and instrumentation diagram*

workstations (for obvious economic reasons).

The newly acquired Atlantic process simulator simulates a typical distillation (depentanizer) process with the equipment and control structure similar to that in industrial plants. The column (seven trays) separates a binary liquid feed mixture containing 60% pentane and 40% hexane by fractional distillation. Figure 1 shows the main menu from which the desired graphic (schematic diagram) can be selected by entering the appropriate "graphic" number. The simulator graphics 1 through 4 are schematic flow diagrams, and 5 through 8 are process and instrumentation diagrams (see Figures 2 and 3). Simulator graphic 9 is the Dynamic Profitability Analysis (shown in Figure 4) which summarizes the cost aspects and keeps updating the profit/loss being made at that particular time. This helps the students gain insight into how process disturbances can affect plant profitability and highlights the necessity of bringing the process back to normal efficiency.

Figure 5 shows the instrument group screen. The set point of any instrument can be changed from this screen by selecting the required loop, and the control valve mode can be changed from automatic to manual in order to alter the manipulated variable. The trend of any instrument can be seen from the group trend screen—the simulator plots the trends of any four instruments at a time, taking either five samples per minute or one sample per minute on a time scale from -12 minutes to 0 minutes. The trends are plotted vertically instead of horizontally. Figure 6 shows the trend of the following instruments when the tower feed pump fails and actions are taken to rectify the disturbance:

1. FI-122 Top product flow indicator
2. FIC-100 Feed flow control valve
3. FI-110 Bottom product flow indicator
4. FI-101 Reboiler steam flow indicator

The simulator runs on two IBM 386 workstations. The hardware for each workstation consists of

- A fully configured IBM 386 with Microsoft DOS 3.2
- Floating point 80387 coprocessor
- 640K RAM
- One serial port
- One parallel printer port with cable
- Monochrome card and monitor with cable
- EGA card (256K RAM) and monitor with cable
- Hard disk
- Two floppy diskette drives
- One Epson dot matrix printer
- Operator TDC 3000 keyboard

The software consists of

- Control System Emulation software
- Instructor Station software
- Pecan Power System Operative Environment
- Process Model

COST

The software, including the operator's keyboard with cable (per unit) costs approximately $25,000 (the listed price as of September 1991), but considerable discount can usually be obtained by educational institutions. The above cost also includes installing the software and training staff to operate the system. All other hardware listed above is extra.

PROCESS MODEL

The Atlantic distillation model is based on first principles of physical phenomena (unsteady state heat and mass balance with thermodynamic properties). It is capable of providing proper dynamic response under normal operations, cold

Atlantic Simulation 0:23

DYNAMIC PROFITABILITY ANALYSIS

DEBITS	COST	USAGE	TOTAL USAGE	$ SPENT	TOTAL SPENT
COLUMN FEED	1.000 $/GAL	148.0 GPM	3915 GAL	8880 $/HR	3912 $
VENTED MATERIAL	67.0 $MSCF	2.77 MSCFH	1.22 MSCF	185 $/HR	82 $
REBOILER STEAM	8.00 $/MLB	9.63 MLB/H	4.25 MLB	77.1 $/HR	34 $
COOLING WATER	0.050 $MGAL	525.0 GPM	13886 GAL	1.575 $/HR	0.694 $
TIME	75 $/MIN	45 MIN	26 MIN	0 $/HR	0 $
OFF-SPEC BOTTOMS	0.040 $/%DV	N/A	N/A	0 $/HR	0 $
OFF-SPEC OVERHEAD	0.030 $/%DV	N/A	N/A	0 $/HR	0 $

CREDITS	PRICE	PRODUCTS	TOTAL PRODS	$ EARNED	TOTAL EARNED
BOTTOMS PRODUCT	1.500 $/GAL	57.8 GPM	1528 GAL	5200 $/HR	2291 $
OVERHEAD PRODUCT	1.250 $/GAL	88.1 GPM	2331 GAL	6611 $/HR	2912 $
OFF-SPEC BOTTOMS	0.020 $/%DV	N/A	N/A	3 $/HR	1 $
OFF-SPEC OVERHEAD	0.035 $/%DV	N/A	N/A	11 $/HR	9 $
BOT COMP (7.8 WT%)	N/A	7.8 WT %	7.8 WT %	N/A	N/A
TOP COMP (93.4 WT%)	N/A	93.5 WT %	93.5 WT %	N/A	N/A
TOTALS	N/A	N/A	N/A	2680 $/HR	1196 $

GRAPHIC: M)enu, N)ext, L)ast, 1)..9)

Figure 4. *Dynamic profitability analysis*

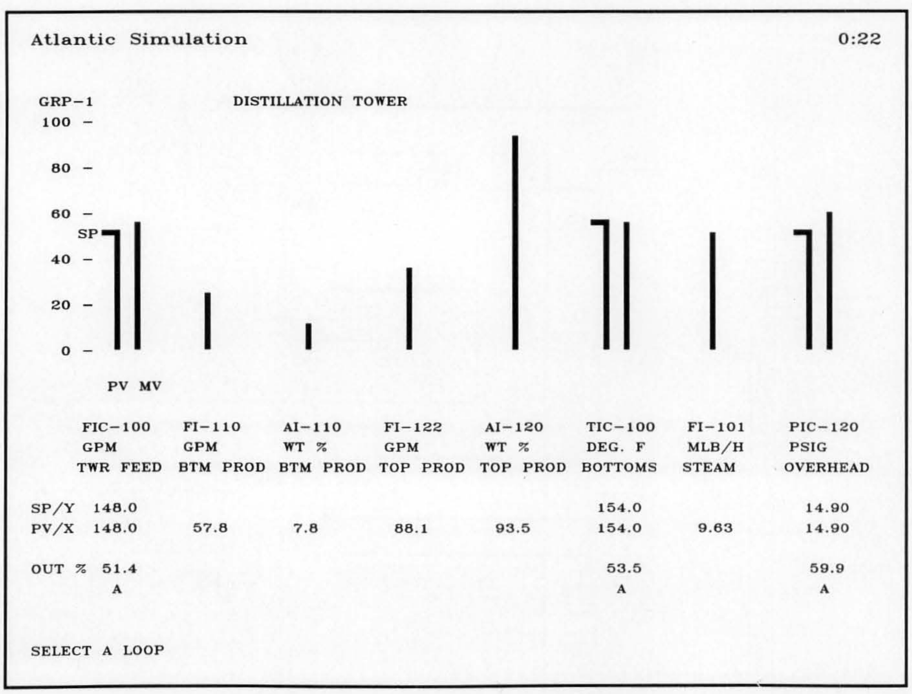

Figure 5. *Instrumenrt group screen*

starts, emergency shutdown, normal shutdown, and plant upsets.

The distillation tower is modeled as approximately eight equilibrium stages. Each stage has few trays, and the vapor and liquid leaving each stage are considered in equilibrium. The dynamic component balance, heat balance, and total mass balance are maintained on each stage of the tower simulation. This assures heat and mass balance at all times in all modes of operation. Based on the tray data, vapor pressure curves are generated for all the components at various temperatures. The vapor pressures of components at startup conditions are also entered into the database along with vapor pressures obtained at design tray temperatures. The stage equilibrium calculations are performed using Raoult's law. The activity coefficient calculations are required if nonideality needs to be considered. The time constants for heat and mass balance equations are based on the mass hold up on the trays and heat capacities. The metal heat capacity can be included but is often ignored to speed up the simulation response time so that a startup can be exercised within a reasonable training session.

All the differential equations for the distillation simulation are solved using the Euler integration method. Because of the steepness of vapor pressures at various temperatures, Atlantic has developed a proprietary subroutine (tray) to solve all the stage differential equations simultaneously using numerical methods.

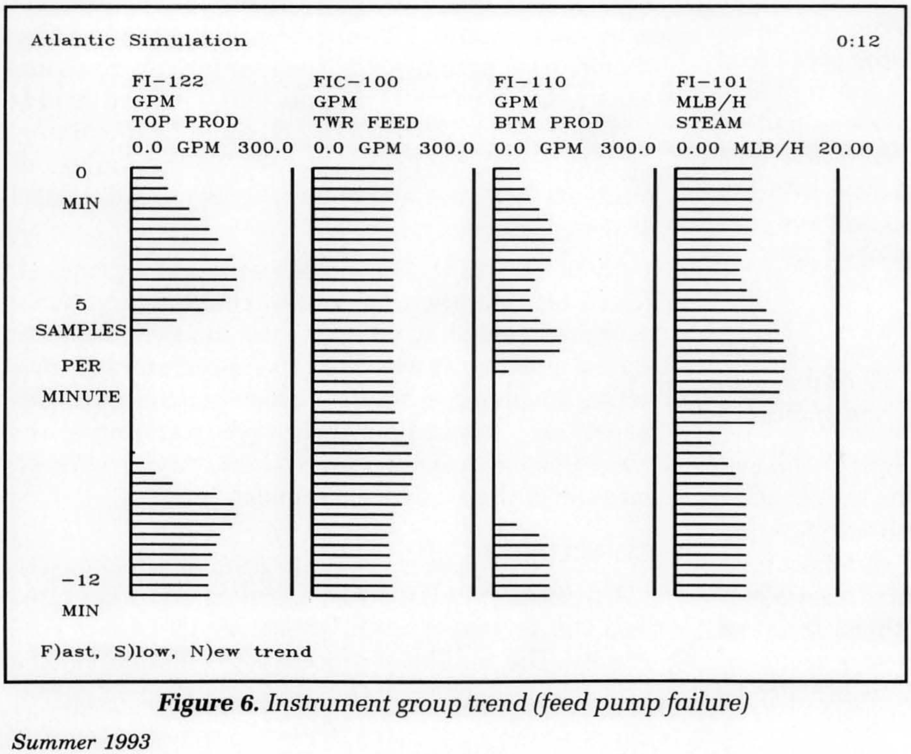

***Figure 6.** Instrument group trend (feed pump failure)*

INSTALLATION

The company recommendation was that the computers be totally dedicated to the simulator, but since the simulator lab is offered only during the spring semester, we did not feel that exclusive dedication of two of our computers to the simulator would be desirable. In order to test the idea of a non-dedicated system, one computer was loaded with the simulator only and the other was loaded with the simulator and additional software. We then checked the performance of both simulators and found that both worked the same. Extra precautions should be taken, however, to ensure that students using other software check their disks for any viruses before inserting them into the computer.

LABORATORY SCHEDULE AND EXERCISES

After allotting time for other experiments and assignments in the process control lab, we were left with only five weeks for the simulator training. With this limited amount of time we had to select a few "typical" exercises from the manual. After we had reviewed the manual, practiced, and trained ourselves, the following program outline was decided upon:

- ***Week 1*** Familiarization with the process, control philosophy, and keyboard operation
- ***Week 2*** Correction of known disturbances
- ***Week 3*** Identification and correction of unknown disturbances
- ***Week 4*** Cold start-up
- ***Week 5*** Buffer for any incomplete work and report submission

The process control lab was scheduled once a week. In order to accomodate fourteen students, we split them into six groups and each group was allotted 1 hour and 50 minutes per session.

In the exercise for correction of known disturbances, the students practiced the corrective actions to be taken when some particular disturbance occurs (*e.g.,* when the feed pump stops, the cooling water block valve closes, the reboiler tube fouls, pentane concentration in feed increases, the ambient temperature changes, etc.).

In the exercise for identification

and correction of unknown disturbances, a disburbance was introduced through the instructor's console and the students had to identify and correct the problem. The time taken by the students to identify the disturbance and to subsequently correct the process was observed.

After the students became familiar with the "normal" operations, they were asked to work on the cold start-up exercise, which gives a step-by-step procedure to start/commission the column. Finally, the students had to submit a report on the whole simulator program.

STUDENT RESPONSE AND PERFORMANCE

Once the students became familiar with the simulator, they showed more interest in the system. In addition to the exercises assigned to them in the lab, some of the students worked on almost all of the equipment failure exercises given in the manual. On the whole, the students' performance in identifying and correcting equipment failures was more than satisfactory. Atlantic Simulation, Inc., recommends certain time limits for identifying and correcting equipment failures: 82% of the students could identify, and 100% of the students could correct, the equipment failures within the stipulated time. Most of the students also successfully completed the cold start-up of the plant to the normal operating conditions.

Most of the student's perception of the overall process was very good, and they learned a number of fundamental aspects of plant operation. For example, when a feed pump fails, after identifying the problem the student would normally start the spare feed pump without realizing that the flow control valve on the pump discharge was wide open as a result of no feed flow—immediately starting the spare feed pump could cause an excess flow of feed into the column, creating more problems. They learned that the flow control valve must be switched over to manual mode and closed to about 20% before starting the spare pump—the valve must be manually opened to obtain the required design flow and then switched back to the automatic mode. Knowing such operational aspects definitely helps young engineers do a better job.

STUDENT FEEDBACK

Since this was the first time the Atlantic Simulator was included in the process control laboratory, we needed feedback from the students to assess how useful the simulator had been to them from an engineer's viewpoint. A questionnaire was prepared for this purpose. We felt the feedback would also be valuable to us in making further improvements in the training program.

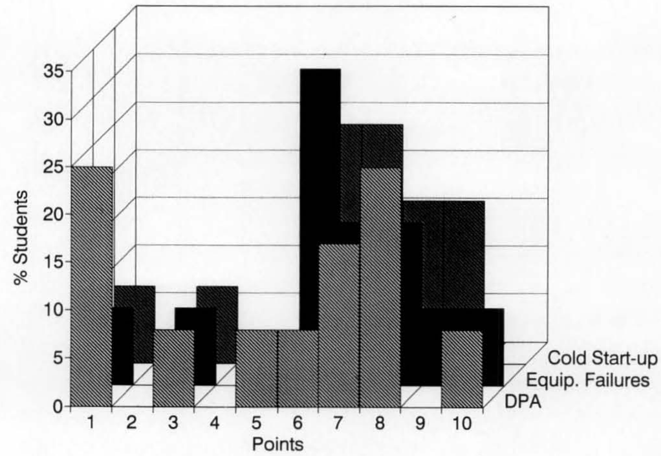

Figure 7. Distribution of student evaluations of the simulator

From an engineer's standpoint, 75% of the students felt that the simulator training was "useful," and 25% considered it "very useful." Figure 7 presents the students' point-evaluation of the equipment failure exercises, the cold start-up exercise, and the dynamic profitability analysis (DPA). It shows that about 67% of the students gave points ranging from 6 to 8 (out of a maximum of 10) for the cold start-up and equipment failure exercises. The students' opinion of the DPA, however, has not been as consistent as in the other two cases.

There is only one cascade control loop in the process, and all of the students said that the simulator did not help them to better understand the concept of cascade control. This could be due to the fact that the program assumes that the user already has some knowledge of control concepts and does not include an explanation. Another reason could be the timing, *i.e.,* the simulator lab was scheduled right after our students have gone through the advanced control scheme lectures.[4]

About 60% of the students wanted more time allotted for this program so they could do additional exercises, including emergency shutdown exercises. To the question of whether other simulators for processes involving reactors, absorption columns, furnaces, etc., would help their understanding of the operation of plants and process control concepts, almost all of the students responded "yes."

CONCLUSION

A process simulator was installed and integrated into the process control laboratory at Lamar University. The simulated process is the distillation of a C5/C6 feed (depentanizer). Based on student performance and feedback, the simulator training is deemed to have been successful. In addition to learning certain fundamental aspects of plant operations and plant-wide process control, the simulator was also useful in emphasizing safety aspects such as emergency shutdown procedures. For new engineers, knowledge of operational and safety aspects could be a real asset when they begin work.

To summarize, the simulator was well received by the students and was regarded by the instructors as an effective teaching tool.

ACKNOWLEDGMENT

Financial support from the Amoco Foundation for the development of the process control laboratory is gratefully acknowledged. We also acknowledge Chetan R. Amin, Mike Kroll, and Joe Siebem for providing us with the details of the process model.

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Continued from page 183.

Experience and judgment are evident in the explanations and discussions of the basic science and industrial usage. A level of comparative knowledge is offered that is often omitted from other texts in favor of physics and mathematics. The reasons why one process is chosen over another in industrial applications are explained. In a section on membrane separations of biological materials, a philosophy is suggested for selecting a process: follow the way in which nature has solved the problem. For example, even though dialysis is a slow process unsuited for large-scale industrial separations, its gentle treatment of blood is appropriate for hemodialysis. The discussion of ion exchange delves into the polymer chemistry of the cationic and anionic resins that facilitate the range of applications of this important unit operation. Motivation is provided for the understanding of drying as a process following evaporation, filtration, or crystallization, to improve handling and reduce transportation costs. A brief description of fluidized-bed catalytic cracking explains the essential features of this outstanding achievement of chemical engineering. Insightful explanations such as these are one reason why this reviewer will open this book before some other engineering handbook when seeking background information on a separation technique.

The topics covered include chapters on: Particulate Solids; Size Reduction of Solids; Motion of Particles in a Fluid; Flow of Fluids through Granular Beds and Packed Columns; Sedimentation; Fluidization; Filtration; Gas Cleaning; Centrifugal Separations; Leaching; Distillation; Absorption of Gases; Liquid-Liquid Extraction; Evaporation; Crystallization; Drying; Adsorption; Ion Exchange; Chromatographic Separations; Membrane Separation Processes.

To illustrate the depth of treatment, consider the chapter on sedimentation. Sections fully describe topics on terminal velocity, height of suspension, shape and diameter of vessel, effects of suspension concentration, Kynch theory, flocculation, settling of coarse particles, and analysis of a continuous thickener. A separate chapter deals with centrifugal separations, including centrifugal pressure and shape of the liquid surface, separation of immiscible liquids, sedimentation, filtration, mechanical design, and equipment descriptions. The chapter on adsorption treats the nature and structure of adsorbents, adsorption equilibria (including mathematics of Langmuir, BET, Gibbs isotherms, and Polanyi potential theory), kinetics, equipment, and regeneration (including thermal and pressure swing, parametric pumping, and cycling-zone adsorption). The exposition of these topics is clear and balanced.

To summarize: this book is a useful and usable contribution to the chemical engineering literature, welcome as an introductory text or as a general reference on separation and particle processes. ❐

ChE book review

PLASTICS RECYCLING: PRODUCTS AND PROCESSES

Edited by R.J. Ehrig
Oxford University Press, 200 Madison Ave., New York, NY 10016; $64 (cloth), (1992)

Reviewed by
Charles Beatty
University of Florida

This is an excellent primer on the products and processes used in the early phase of plastics recycling. It covers the commodity plastics that are available for recycling in reasonable volumes. For this

Continued on page 219.