A *NEW* TRADITIONAL UNIT OPERATIONS LABORATORY COURSE

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In 1968 the Department of Chemical Technology, the Technical University of Denmark, moved from an old location in central Copenhagen to a modern, spacious campus north of town. The department was given adequate funds to develop new laboratory courses, and a new, traditional unit operations laboratory course is now completed. It is the purpose of this communication to describe the course in some detail so that other chemical engineering departments may benefit from this experience. The author will gladly furnish further information regarding details of the course upon request. Before proceeding further, it is necessary to explain the purpose of the course.

PURPOSE OF THE COURSE

It is characteristic for the Danish chemical industry that it consists of many rather small units. One can therefore not depend on the industry to give chemical engineering graduates a professional, rounded technical training program. This, and the fact that the ChE students are subjected to a thorough physics laboratory course early in the curriculum, indicate that in designing the unit operations laboratory course, one should emphasize real process equipment rather than physical phenomena. That is to say that the course should be based on equipment resembling process equipment rather than transport phenomena experiments.[1]

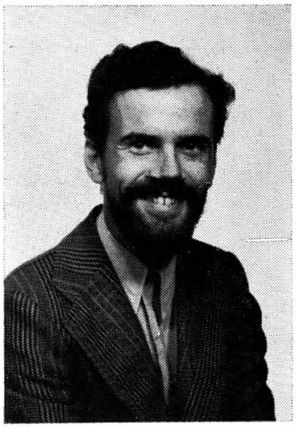
In the foreword of the laboratory manual[2] for the course the purpose is stated as follows:

- To give an understanding of and a physical feeling for the processes and transport phenomena taking place in large scale chemical processing equipment.
- To show how the principles developed during the lectures in unit operations may be used in designing and running processing equipment.
- To furnish insight into how the unit operations used in the chemical industry work and the limitations of these.

These purposes have had a large influence on the design of the equipment for the experiments. One might say that the course constitutes a "movement" away from transport phenomena laboratory type equipment. This does not mean, however, that transport phenomena type measurements (for example, single film heat transfer coefficients as opposed to overall coefficients) are not carried out in the course. Indeed they are, but the tendency is to perform the measurements in process equipment so that the students do not have to extrapolate from model experiments to real life. It is understood that a similar "movement" is taking place in several ChE departments in the US.

COURSE CHARACTERISTICS

The course is offered twice a year in three-week periods during which the students devote their full attention to the course. The maximum number of students is 70 per three-week period. Since this is an introductory course, it was found best to expose the students to as many different unit operations as possible. For pedagogic reasons it was decided to work with small teams of students (two per team). For these reasons, a relatively large number of experimental units was found necessary. It was also found necessary for the students to work with ready-made experimental units. If the students were to construct the equipment themselves, many of the course



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objectives could not be achieved. Later on in the curriculum, the students have a chance of constructing their own equipment during (required) senior thesis work.

Altogether 27 experiments have been designed and constructed, and these experiments are divided into nine groups, each containing three similar (but not identical) experiments. The students must not have more than one experiment from each group. The experimental units are described briefly below.

Before each experiment is to be performed, the students are briefed as to the operating conditions and the report requirements. A variety of possibilities, is built into most experiments. It is found that the students can carry out the experiments with the aid of the laboratory manual[2] without much further supervision and that they find the experiments quite challenging. The corrected reports are, of course, discussed with the students, who at the end of the course receive a "pass" or "fail" on the basis of the reports.

The laboratory course is housed in two adjacent localities: an apparatus hall of ceiling height 7 m, containing a small area with ceiling height 16 m, for pilot scale experiments and an ordinary laboratory for bench scale experiments. Both locations are provided with ample steam, water, gas, and electrical supply.

EXPERIMENTS

A short abstract is given for each experiment below. A capital letter in the experiment number (e.g. 1A) indicates that the experimental unit is placed in the apparatus hall, and a small letter (e.g. 1b) indicates that the experimental unit is located in the ordinary laboratory.

1. **FLUID FLOW.** Flow of water in pipes. Flow of water in tubing. Flow of air in ducts.
2. **FLOW OF FLUIDS THROUGH POROUS MEDIA.** Filtration. Fluidization. Flow through packed columns.
3. **EVAPORATION AND CONDENSATION.** Evaporation in a vertical tube. Evaporation in a vertical tube. Condensation.
4. **HEAT EXCHANGE.** Heat transfer in pipes. Heat transfer in pipes. Unsteady state heating of water.
5. **DISTILLATION.** Distillation in a bubble cap column. Simple and batch distillation. Continuous distillation.
6. **ABSORPTION.** Absorption in a packed column. Absorption in a bubble column. Absorption in a sieve tray column.
7. **SIMULTANEOUS HEAT AND MASS TRANSFER.** Drying. The wetted wall column. Air humidification in a spray tower.
8. **EXTRACTION.** Extraction in a rotaing disc column. Extraction in a reciprocating plate column. Extraction in a mixer-settler.
9. **OTHER UNIT OPERATIONS.** Preparative gas chromatography. Reverse osmosis. Crushing and grinding.

The experiments do not, of course, cover the whole field of unit operations. The very important area of crystallization is, for example, omitted. However, they should ensure that the students come in close, practical contact with a broad spectrum of chemical processing equipment.

REMARKS

The experience with the course has generally been good. The students and faculty seem to find the course an interesting worth-while experience. As mentioned above, one argument against a course of this type is that using finished, fixed experimental units does not leave much room for student initiative. However, this was recognized as a danger from the very beginning of the planning, and attempts have been made to make the course as interesting and challenging as possible in other ways. Where possible, large scale glass equipment is used so that one may visually observe the phenomena of interest. Adequate instrumentation has been provided so that many tedious measurements are avoided and so that the students may concentrate on the central problems (on the other hand, automation is kept to a minimum as "push-button experiments" are not desired). In addition, the fact that most of the experiments are concerned with separation processes, a specialty of chemical engineering, stimulates interest.

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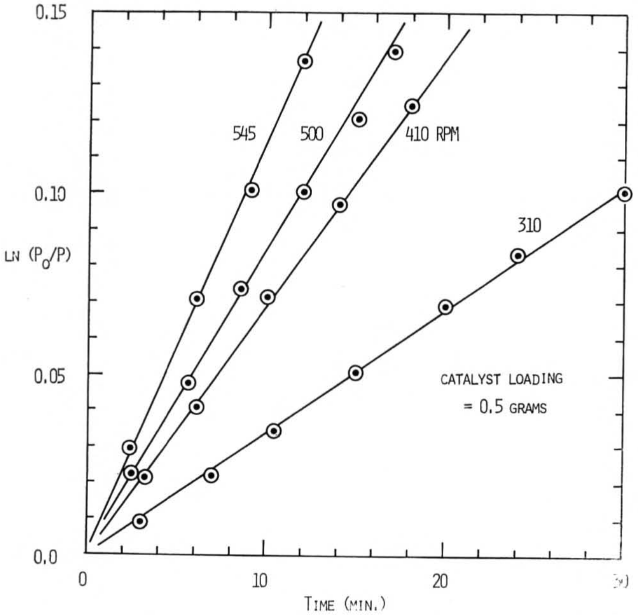

Fig. 9. Pressure ratio verses time and mixing rate for nitrobenzene hydrogenation.

be calculated. Theoretically the expected behavior is first order with the effective reaction rate constant being dependent on temperature, agitation rate, and catylyst loading. Figures 8 and 9 illustrate the type of data which is obtained. The first order behavior is verified and rate constant dependence on catalyst loading and agitation rate is shown. Figure 10 summarized the results of Figure 9, giving the reaction rate constant as a function of mixer RPM. The high RPM asymptote corresponds to chemical reaction rate control and the low RPM asymptote results from a diffusion controlled regime. Data at temperatures other than room temperature would allow for the determination of the activation energy and preexponential factor of the chemical reaction rate constant. Empirical correlations for catalyst loading and RPM (or mixing power input) are also possible alternatives.

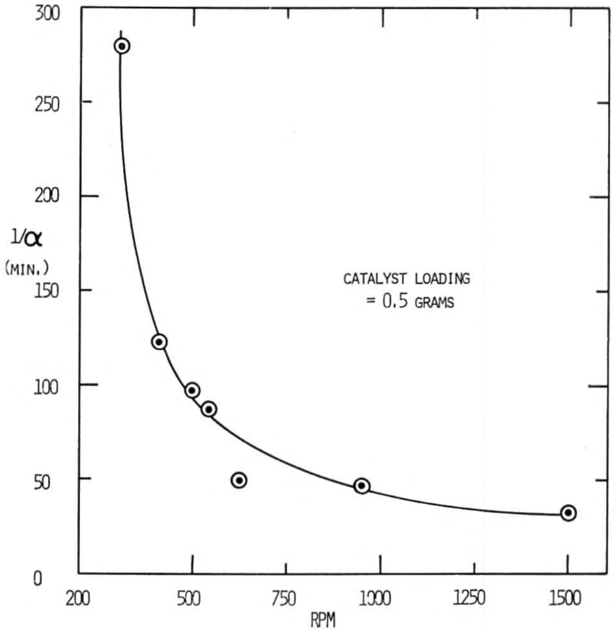

Fig. 1. Effective rate constant verses mixing rate for nitrobenzene hydrogenation.

Other heterogeneous experiments which are currently under development include the high temperature, noncatalytic regeneration of coked Thermofor catalytic cracking catalyst and the leach recovery of metals (e.g., copper) from their ores.

ACKNOWLEDGMENT

In developing such a laboratory one should be alert for experiments which others have developed which have proven to be successful and which complement the laboratory objective. In this regard, I must acknowledge the use of ideas of Drs. James B. Anderson at Yale and Gordon B. Youngquist of Clarkson They have been especially helpful in suggesting experiments which we have used successfully.

FREDENSLUND: (From page 143)

The stated course objectives appear to have been met satisfactorily, although improvements in the course are still being—and will continue to be—made. Before starting the design of a course of this type, the purpose of the course must be very clear, since the equipment design may vary a great deal with the objectives. These objectives are likely to differ somewhat from department to department.

ACKNOWLEDGEMENTS

The author wishes to thank all colleagues in Lyngby, Lund, and Trondheim, who have contributed to the development of the course.

REFERENCES

1. Crosby, E. J., "Experiments in Transport Phemoment", Wiley, New York, 1961.
2. Fredenslund, Aage, "Experiments in Unit Operations", Den private Ingeniofond, Copenhagen, 1972 (270 pp. in Danish).