ChE laboratory

USING THE LABORATORY TO DEVELOP ENGINEERING AWARENESS

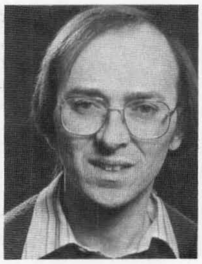
R. ENGLAND and R. W. FIELD
University of Bath
Claverton Down, Bath, BA2 7AY, England

The Professional Institutions Directorate of the Engineering Council (of the United Kingdom) issued guidelines in 1983 for the training of all undergraduate engineering students in Great Britain who wish to attain chartered engineering status. These proposals subsequently became mandatory in 1985 and included the requirements that all courses accredited by the Engineering Council contain a minimum level of Engineering Applications 1 (EA1) and Engineering Applications 2 (EA2) by the start of the 1988 academic year. For chemical engineering these are defined as:

- **An introduction to the methods of fabrication, selection of materials of construction, and operation of chemical process plant hardware, giving due consideration to the interaction of these factors on costs, safety, operability, and reliability.**
- **The application of engineering principles to the solution of practical process engineering problems.**

In the UK it has been common for most chemical engineering courses to integrate the practice of process engineering and to seek real solutions to practical problems. Thus, few modifications were necessary to meet the requirements of EA2. However all UK courses needed enhancement in order to meet the EA1 proposals of the Engineering Council. The focus of this paper is on the changes made to the undergraduate laboratory progamme of the chemical engineering first degree course at the University of Bath. These changes have been introduced in order to meet the Engineering Council requirements and to develop a greater student awareness of engineering concepts.

Richard England graduated in chemical engineering at the University College, Swansea, University of Wales. He is a lecturer in the School of Chemical Engineering at the University of Bath. Research interests are in biotransformation, downstream processing, and membrane separations.



Robert Field obtained his BA and PhD degrees from the University of Cambridge. He is a lecturer in the School of Chemical Engineering at the University of Bath and is author of the book *Chemical Engineering: Introductory Aspects* (Macmillan Education). Research interests center on heat, mass, and momentum transfer

BACKGROUND

Before moving on to the detail, a contextual introduction is given. Most students entering the chemical engineering course at Bath have specialized in three sciences at the secondary school level and have attained at least three General Certificate of Education qualifications at the advanced level (usually in chemistry, physics, and mathematics). The student has little or no knowledge of engineering subjects, and practical experience is limited since the trend in recent years has been to reduce the amount of laboratory work at secondary schools (mainly because of financial considerations). Although the student may have visited companies or listened to talks from visiting engineers, his concept of engineering is often flawed. They are often unaware of the probability of multiple solutions to a problem and have no idea of the technical difficulties encountered in design and construction of processing units.

The Chemical and Bio Process Engineering degree course at Bath endeavours to provide a solution to some of the problems and to instill engineering awareness in the student. For most students, a year-long industrial placement is an integral part of the degree scheme. The placement is undertaken as the third year of a four-year course, and a position as a trainee engineer within a company or research establishment is found by the University. Not only is the relevance of

. . . a year-long industrial placement is an integral part of the degree scheme. It is undertaken as the third year of a four-year course, and a position as a trainee engineer within a company or research establishment is found by the University. . . . progress of the student is monitored both by the company and by his industrial tutor.

the academic course highlighted for the students, and knowledge consolidated, but valuable practical experience is also gained. During this period progress of the student is monitored both by the company and by his industrial tutor. An improved appreciation of financial constraints and the importance of communication skills is obtained, and the student's subsequent development during the final year of the degree scheme is enhanced.

THE BATH APPROACH

Engineering awareness is developed from the very beginning. Students entering the department are given a week-long course which introduces them to the various core subjects of chemical engineering and their relation to the "process dimension." The process dimension is seen to be the main characteristic of chemical engineering and can be defined as "the ability to break down into its component parts a manufacturing process in which matter is transformed or chemically changed to provide a specification for each subdivision, and to recombine the whole into an economical, workable, and maintainable plant." This is achieved by means of overview lectures, a preliminary design assignment, and industrial visits.

In the third term of each year the students undertake a design project which has been chosen to show the relationship between chemical engineering fundamentals, engineering practice, and the enabling science (mathematics, economics, chemistry, *etc.*) which they have been taught during the year. The design projects are chosen to complement the courses, to provide experience in teamwork, and to develop awareness of the practice of chemical engineering.

The first year design project is usually a mass and energy balance and flow sheeting exercise on a well-documented process. The second year design is used to draw comparisons between existing processes and less conventional routes, *e.g.*, the production of n-butanol by chemical and biochemical routes. In the final year, senior chemical engineers from industry suggest the original problem specification, provide technical input when information is not available in the open literature, and lead discussion groups. This work involves projects requiring the latest technology, *e.g.*, off-shore gas-oil separation, destruction of toxic wastes, and microbial production of *cis*-1,4-polyisoprene.

A major element in developing engineering awareness during the first two years of the degree scheme is the undergraduate laboratory programme. The rest of this paper is devoted to those elements of the programme which relate to EA1.

UNDERGRADUATE LAB: EA1 Experiments

The experiments relating to the EA1 requirements, which comprise approximately 30% of the total first and second year laboratory programme, can be summarized as follows:

1st Year Experiments

- **The design and construction of a pumping circuit involving leak testing, calibration of instruments, and characterization of the pump**
- **Start-up, operation, manual control, and monitoring of pilot plant equipment, *e.g.*, double effect evaporator and batch packed distillation column**
- **The problems of measurement and choice of transducer, *e.g.*, temperature, pressure, and viscosity measurements using various measuring devices**

The object of these experiments is to demonstrate the difficulties that can be encountered in "simple" measurements and relatively "straightforward" processing equipment, and to establish the need for engineering input.

2nd Year Experiments

- **Start-up and operation of a steam boiler (capacity 2000 lbs per hour steam at 150 psig)**
- **Hazard and operability study (HAZOP) of a batch distillation column**
- **Disassembly and reassembly in a different configuration of a plate heat exchanger and analysis of thermal performance**
- **Work permit preparation for the modification of a number of pieces of process equipment, *e.g.*, cooling tower and distillation unit**

Process safety has deliberately been included in the experimental programme to complement the lecture courses on process design and development and loss prevention, and to emphasize the need for chemical engineers to be aware of, and to actively include, safety in all aspects of their work.

FIRST YEAR EA1 EXPERIMENTS

The experiment (see Table 1) requiring the calibration of certain devices for temperature measurement and for viscosity measurement was introduced in 1982 because students had misconceptions about the meaning of accuracy, particularly with reference to the calibration of instruments.

The first part of this experiment requires the calibration of a number of temperature measuring devices against a standardized National Physics Laboratory thermometer and, if possible, comparison of the values obtained with theoretical values from the literature, *e.g.*, e.m.f's of thermocouples. The equipment consists of a thermostatically controlled water bath, a multimeter, and various temperature measuring devices which can all be purchased for approximately £1300. The students invariably report the results in terms of the accuracy of one device, *i.e.*, deviation from a straight line or a smooth curve when compared to the others, without consideration of the sensitivity of the device or the limits on reading the scales on the instrument.

The second part of the experiment is the determination of the viscosity of carboxy-methyl-cellulose solution using three different techniques. The only expensive item of equipment is the rotating cup viscometer, which costs approximately £1000. Students are given references for the different methods, but are not told that the fluid is non-Newtonian. The apparatus for the falling sphere method was chosen to give very small fall times, thus making the main experimental error the timing of the fall of the sphere. Typical conclusions drawn by the students were that only the rotating cup method was "accurate" and that the other techniques were not suitable for determining viscosities, in spite of the fact that they were given the literature references and informed that these are standard methods for determining viscosity. Only about 10% of the students concluded that the techniques being used might not be suitable for the range of viscosities being studied.

Oral presentation of results (in the presence of their fellow students) is required for these experiments, and it enables us to make students aware of the difference between errors resulting from the calibration of an instrument, the accuracy of an instrument based on theory, and the method of calibration. It also illustrates some of the pitfalls to be avoided when using results from measurement devices and fosters discussion of the limitations of the various measurement techniques and the problems of departure from ideality.

The experiment dealing with the operation of a double effect evaporator (see Table 2) was designed to give experience in start-up, steady-state operation, and shut-down of a pilot plant. The equipment, which would have cost in the region of £40,000 to purchase, was donated to the department. Only manual control is provided on the equipment, and hence the students experience difficulty in obtaining and controlling the unit at steady-state. This experiment gives most students their first hands-on experience with equipment of a reasonable size, and their reactions have been mixed. Generally they have found it enjoyable to operate a pilot scale unit. However, the difficulties already referred to limit the amount of meaningful data on the performance of the evaporator, and this has been frustrating. In reporting their results, nearly all the students refer to the need for better control so that steady-state operation can be obtained.

The operation of a packed, batch distillation column, 80mm diameter, with a packed height of 1.7m, gives the students their first exposure to distillation on any pilot or larger scale. Their experience has usu-

TABLE 1
Calibration of Temperature Measuring Devices and Measurement of Viscosity

Time allowed for experimentation: 4 hours

Experiment requires:

Part A:
- Calibration of the following devices using a standardised National Physical Laboratory thermometer:
  - Mercury-in-glass thermometer
  - Thermistor
  - Platinum resistance thermometer
  - Type T and type K thermocouples
- Comparison of results with data from literature

Part B:
- Measurement of viscosity
- Preparation of a carboxy-methyl-cellulose solution (range 0.5 to 1.5 w/w%)
- Determination of viscosity at 20°C and 35°C using
  - Falling sphere method
  - Rotating cup
  - Ostwald viscometer

TABLE 2
Operation of Double Effect Evaporator

Time allowed: 7 hours
(Capacity of evaporator - nominal 800 kgh^{-1})

Experiment requires:
- Start-up of evaporator
- Steady-state operation using manual control
- Mass and energy balances over evaporator
- Shut-down of evaporator

ally been limited to small scale bench distillations in chemistry practicals, using standard glassware. They are asked to start-up the column and to operate at total reflux to determine heat losses. Then they must choose a reflux ratio and carry out a mass balance for the time of operation. Their main reaction is surprise at both the length of time required ($\simeq$ 3 hours) to reach equilibrium at total reflux and the poor thermal efficiency. The latter is mainly due to the large heat losses from the unlagged reboiler.

Written reports in the form of a technical letter giving a brief outline of the experiment, together with the results, a brief discussion, conclusions, and recommendations are required for the above two experiments. The students are graded by evaluating the report and by monitoring their approach during the experimentation.

The experiment in which the students design, construct, and test a pumping circuit is detailed in Table 3. The equipment consists of standard "off the shelf" items and costs approximately £1250 per rig. The items provided enable a number of different circuit configurations to be constructed.

The experiment has been invaluable in demonstrating the problems involved in the design of even simple rigs. This is particularly true for students who have little or no previous practical experience who make mistakes in the design and construction of the pumping circuit. We hold discussions with each student pair to point out errors in their design construction and to suggest improvements before they attempt to construct the rig. After the rig is built, tests are carried out to leak test, to characterize the pump, and to carry out the other tasks detailed in Table 3.

TABLE 3
Design and Construction of Pumping Circuit

Time allowed: 15 hours

Experiment requires:
- Design of circuit
- Construction of circuit
- Leak testing
- Determination of flow rate versus head characteristics of pump

The following components are provided:
- Rotameter
- Pump (dismantled)
- Bordon pressure gauge and pressure transducer and indicator
- 'V-Reg' valve and globe valve
- Two tanks and framework
- Q.V.F. pipe sections, elbows, tees, hose connectors and couplings
- Various pipe fittings and flexible hose

The student must determine:
- The circuit design for characterisation of pump and leak testing
- Calibrate one of the pressure measuring devices using a 'dead weight tester' before inserting in circuit
- Use calibrated pressure gauge to calibrate other gauge *in-situ*
- Calibrate *in-situ* the rotameter
- Determine flow rate versus head characteristics of pump

> **Since an engineer is effective through what he does rather than through what he knows or could do, it is important that engineering students acquire not only understanding and practical experience, but also speaking, writing, and calculation skills.**

The lessons learned by the students during their first year laboratory sessions on EA1 can be summarized as follows:

- **Instruments are only as accurate as their calibration**
- **Instruments must be chosen with a particular task in mind**
- **Effective control of a unit must be carefully thought out; the effect of altering one parameter may have considerable effect on other parameters and the overall operation of the unit.**
- **Manual control can be satisfactory but is limited to some simple systems**
- **The time for a system to reach steady-state conditions can be long**
- **Multiple solutions exist even for simple design problems**
- **An appreciation is gained of the practical difficulties encountered in the construction of units consisting of a variety of materials and components**
- **The importance of effective communication skills is demonstrated**

SECOND YEAR EA1 EXPERIMENTS

Although it can reasonably be argued that students have already acquired a good level of understanding of safe working procedures, this key area is now emphasized, through both existing and new experiments. The expediture for the following experiments was less than £250 since most of the necessary equipment was already installed.

The batch distillation of an organic mixture in a steam heated boiler is undertaken by all students, working in pairs. In addition to the traditional analysis (for example the calculation of the HTU of the packing), a hazard and operability study is required [2, 3, 4]. The latter forms the main focus of the reports produced by the students.

The Work Permit assignment (Table 4) requires the students to read four official Health and Safety Executive (HSE) guidance notes [5, 6, 7, 8]. They must then prepare a work programme and issue a work permit for 1) the replacement of a condenser on a batch distillation column and the repair of a weld fracture on the vapour return line of the reboiler, and 2) entry into an induced draught cooling tower to inspect the fan.

Students are not required to produce a formal report of this assignment, but they must submit material which would reflect the way in which the information could be presented at a preliminary meeting of the plant supervisor, the plant engineer, the maintenance supervisor, and the safety officer. In common with the previous assignment this is undertaken, in turn, by all of the second year students.

A third task, undertaken by some students, is to witness the start-up of the department's package steam boiler, to report on the start-up and shut-down procedures currently used, to identify the hazards, and to note key operating parameters (see Table 5). By way of preparation, a HSE guidance note on the operation of automatically controlled steam and hot water boilers [9] is studied.

The fourth and last task relating to EA1 illustrates how a traditional experiment can be modified to include an EA1 component. In the past, students have used a small plate heat exchanger to evaluate the dependency of heat transfer coefficients and the pressure drop on fluid flowrates. The practical exercise of changing the plates and leak testing was introduced two years ago. The students complete the performance analysis, devise and discuss a safe procedure for changing the plates, and then carry out the task. As with the other EA1 assignments, it is relevant and is enjoyed by the students, making them more receptive to the lessons embodied in the experiment.

DISCUSSION

At Bath all EA1 learning is woven into the degree scheme, and it is apparent that the students are receptive to this approach. Not only are additional demands on the students' time minimized, but also the relevance of the EA1 and EA2 material to process engineering is clear.

An alternative approach reported by others [10] includes an EA1 module on the dismantling, inspection, reassembly, adjustment, and testing of a safety valve. However, most students see this as a task where the principal objective is simply overhauling and testing a safety valve as quickly as possible. The originators of this task had thought that the principles underlying the activity would be an appreciation of the construction and functioning of the valve, and not the manual task itself. This problem indicates that if EA1 learning is to be educational (as opposed to mere training), then it must be an integral part of the course.

Since an engineer is effective through what he does rather than through what he knows or could do, it is important that engineering students acquire not only understanding and practical experience, but also speaking, writing, and calculation skills. The engineering application tasks outlined above have proved to be efficient learning experiences. Through the setting of education tasks it has been possible to assess students in this area. Previously, the development of engineering awareness was a valued but unquantified by-product of a traditional course of study. The students' experimental and design reports now reflect a better understanding of engineering practice (as well as engineering principles), and they are more fully prepared for their industrial placement and final year of study.

The inclusion and integration of EA1 and EA2 material into the Chemical and Bio Process engineering degree course at Bath has met the requirements of the Engineering Council, and re-accreditation of the course has recently been granted. Students graduating with an Honours degree are exempt from educational requirements for Chartered Engineer status and Cor-

TABLE 4
Work Permit

Time allowed: 4 hours

Assignment requires:
- Study of Health and Safety Guidance Notes
- Familiarisation with proposed maintenance work
- Familiarisation with use and application of flammable gas detectors
- Production of report proposing work programme

TABLE 5
Steam Boiler Operation

Time allowed: 4 hours

Assignment requires:
- Study of Health and Safety Guidance Notes
- Study of manufacturer's instruction manual
- Witnessing of boiler start-up
- Production of report: start-up and shut-down procedures, identification of hazards, and record of key operating parameters

porate membership of the Institution of Chemical Engineers.

CONCLUSIONS

A number of Engineering Applications related experiments have been introduced into the course by modifying existing equipment and by provision of new items at a cost of $\simeq$ £6000. The changes have given the students more hands-on experience in the laboratory and have encouraged an engineering approach to problems. The pumping circuit equipment allows the students to develop their own thinking on the construction and functioning of a simple rig, and it lets them make their own mistakes under carefully controlled and safe conditions.

Overall it has been found that the students are responding to this approach and are more receptive to the laboratory sessions. Their laboratory reports reflect both an increasing awareness of a practical engineering approach and improved communication skills.

ACKNOWLEDGEMENT

The authors acknowledge the support of other members of the School of Chemical Engineering in the development of the laboratory programme.

REFERENCES

1. Levy, J. C., *Standards and Routes to Registration (1985 Onwards),* The Engineering Council, London (1983)
2. Kletz, T. A., *HAZOP and HAZAN: Notes on the Identification and Assessment of Hazards,* Institution of Chemical Engineers, London (1983)
3. Kletz, T. A., "Eliminating Potential Process Hazards," *Chemical Engineering,* 48, (April 1985)
4. Lees, F. P., *Loss Prevention in the Process Industries,* Butterworth, London (1980)
5. Health & Safety Executive, *Entry into Confined Spaces,* Guidance Note GS5, HMSO, London (October 1984)
6. Health & Safety Executive, *Industrial Use of Flammable Gas Detectors,* Guidance Note CS1, HMSO, London (September 1979)
7. Health & Safety Executive, *Safety in Pressure Testing,* Guidance Note GS4, HMSO, London (July 1977)
8. Health & Safety Executive, *Electrical Apparatus for Use in Potentially Explosive Atmospheres,* Series booklet HS(G)22, HMSO, London (1984)
9. Health & Safety Executive, *Automatically Controlled Steam and Hot Water Boilers,* Guidance Note PM5, HMSO, London (September 1985)
10. Mattews, A. T., A. N. Main, and G. S. G. Beveridge, "Getting Experience," *Engineering Design Education,* Design Council, 2-5 (Spring 1985) ❒

ChE book reviews

CHEMICAL REACTION AND REACTOR ENGINEERING

edited by James J. Carberry and Arvind Varma
Marcel Dekker, Inc., New York, NY 10016; 1088 pages, $150 (1987)

Reviewed by
Anthony G. Dixon
Worcester Polytechnic Institute

This book is made up of fifteen chapters on various topics in reaction engineering, by leading workers in the field. It is similar in concept to the Wilhelm memorial volume of ten years ago (*Chemical Reactor Theory. A Review,* L. Lapidus and N. R. Amundson, eds., Prentice-Hall, 1977), but strikes a much more even balance between theory and application. The editors claim the book to be "hardly a textbook or a handbook," but most chapters have aspects of both functions. Practitioners will find it a useful reference, while teachers will want to assign particular chapters as collateral reading for graduate courses in reactor design and related areas. The production of the book is high quality, with uniform type and illustrations for all chapters, which has had some trade-offs in terms of the high price and the delay in publishing–the almost complete lack of references after 1983 belies the 1987 publishing date.

General topics are covered first. Villadsen and Michelsen open with a chapter on numerical methods, beginning with a short review of basic techniques. Most of the chapter emphasizes collocation methods, especially newer developments. A section on parameter estimation is most welcome. Shinnar's chapter on residence-time distributions gives a clear exposition of the limitations of the method, marred only by the many typographical errors. The author eschews mathematical complexity in favor of conceptual understanding and common sense.

In their chapter on catalytic surfaces, Delgass and Wolf provide an excellent guide to the alphabet soup of surface analysis and catalyst characterization techniques. They explain what each technique is used for, basic principles, equipment, interpretation of data, and difficulties. Both surface and adsorbed species methods are covered.

Diffusion and reaction in catalyst pellets is covered by Luss in a chapter that provides a comprehensive literature survey. The emphasis is less on physical insight and more on the mathematical development. A good section on effectiveness factors is provided. Doraiswamy and Kulkarni cover gas-solid noncatalytic reactions, beginning with single pellet models and moving to reactor

Continued on page 153