AN ENGINEERING APPLICATIONS LABORATORY FOR CHEMICAL ENGINEERING STUDENTS

W. A. Davies, R. G. H. Prince, R. J. Aird[1]
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The department of chemical engineering at the University of Sydney has recently commissioned a new laboratory for first-year students. In a break from traditional introductory undergraduate practical work which was confined largely to chemistry and physics laboratories, this new venture puts undergraduates face-to-face with an authentic process engineering plant during their first weeks at the university.

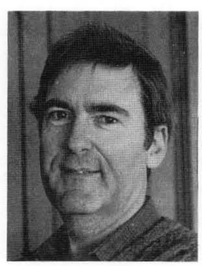
In a closely-supervised environment, student groups are confronted with rigs built from full-sized industrial machinery and equipment. They must draw a flow sheet, dismantle and draw key components, reassemble the parts, operate the rig, and interpret the run data.

The laboratory, which completed its inaugural semester in the first half of 1989, received immediate approval from the students, who felt that the experience identified them as engineers from the outset of the course. This was a most gratifying response, especially since one of our major goals was to integrate the practical and the theoretical aspects of engineering and to do so in an interesting and relevant way.

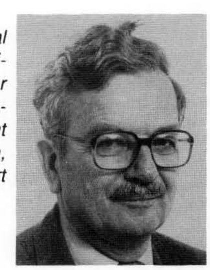
In this article we will describe both the physical features of the laboratory and the nature of the course built around it.

LABORATORY HARDWARE

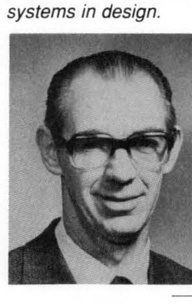
There are eleven rigs, of which eight are near-duplicate pairs. The rigs are built around key components comprised of process pumps, control valves, steam traps, shell-and-tube heat exchangers, a plate and frame filter press, a pressure-relief valve, and a parallel-plate heat exchanger. Each rig performs a simulated process. The pumps recirculate water from a tank through a network of valves and flow meters; the plate heat exchangers heat a viscous process fluid using steam and then cool it using water; the pressure relief valve lets air out of a holding tank when it is set above a certain pressure. Each rig is equipped with measuring instruments which are appropriate to the task, such as pressure gauges, flow meters, temperature gauges, and motor-speed indicators.



Wayne A. Davies *received his BSc and PhD at the University of Sydney. After several years in biomedical research he returned to mainstream engineering with strong interests in biological process engineering, computerized control, and mineral processing. He is a consulting engineer on a wide range of problems for industry and government, mainly in risk management and waste disposal, and teaches part-time in the department at the University of Sydney.*



Rolf G.H. Prince *received his BE degree in chemical engineering in New Zealand and his PhD at the University of Sydney. He was the Foundation Professor of Chemical Engineering at the University of Queensland and has been head of the Sydney department since 1969. His research interests include distillation, process modeling, fuel alcohol, and the use of expert systems in design.*



Robert J. Aird *received an honours degree in mechanical engineering from the University of Durham (UK). He has worked for the UK Atomic Energy Authority and for Canadian Westinghouse, as well as holding a long-term appointment at the Loughborough chemical engineering department, where he has interests in plant reliability and energy monitoring. He currently works for Brush Electrical Machines Ltd., a division of Hawker Siddeley.*

[1] Loughborough University of Technology, Loughborough, Leicestershire, England LE11 3TU

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LABORATORY PROCEDURE

In the first stage of the work, students must become familiar with the rig, its construction, and its function. Students are provided with notes which give a general introduction to the rig and go on to describe, in detail, the exact method of dismantling the key component. They are instructed to study each rig carefully, referring as needed to literature which is permanently on display in a notice-case outside the laboratory. All valves are uniquely numbered, and a key in the notes describes each by a functional name. Students must draw a flow sheet, using accepted process symbols, and label it appropriately. During this time they are quizzed by the demonstrators to determine their level of competence to proceed to the next stage.

In the second stage students dismantle a key component of the rig and then return it satisfactorily to service. To do this safely, it is necessary to shut down the rig and to isolate it from all sources of energy. Following standard industrial safety practices, students must submit a "permit-to-work" form, describing the work they intend to do, to their supervisor. If all is in order, the supervisor signs the form and proceeds to lock off the electricity, steam, or compressed-air supply as appropriate.

During dismantling, students learn the correct names of machinery parts and of the tools used. They also get a feeling for the design and the materials used, as well as for the logical order of doing work on a piece of equipment. Having disassembled the component, the students then make a drawing of its key features. These may vary from intricate exploded views of the pumps or safety-relief valve, say, to simpler drawings of the internals of a heat exchanger. They then reassemble the unit. If the supervisors agree that it has been returned to an operational state, they sign the "return-to-service" section of the permit and remove the lock from the energy supply.

In the third stage, students start up the process and check to see that it is operating satisfactorily (hoping they will not find any malfunction which would involve a time-consuming dismantling job). Upon startup, the students ensure that all process parameters (such as pressures, temperatures, and flowrates) are in their correct ranges and that no leaks are evident. They must then vary an important parameter, such as the flowrate or valve position, and observe the effect on a measured value somewhere in the system. Simple calculations are done (such as heat and mass balances) and relevant data are plotted.

In the final stage students present their findings, which are written in a workbook. Their report contains the flowsheet and exploded drawings of key components of the rig, together with answers to set questions in the notes and answers to spontaneous questions asked by the demonstrators. The entire laboratory session is rigidly confined to a three-hour period, and all writing must be done in that time. At the end of the session books are handed in for grading.

EQUIPMENT AND PROCEDURE DETAILS

• *Control Valve* •

Each of the two rigs include a pumped recirculation loop which conveys water from a header tank, through a control valve and flowmeter, then back to the tank. The control valves are isolatable with manual gate valves so that they can be dismantled without having to empty water from the entire system. Students must dismantle the valve to display the plug and seat.

The two valves dismantle in different ways, and the two student groups compare valve construction with each other—especially the shape of the plug, which is sketched as a record. Upon reassembly, the relationship between the valve plug and seating and the position of the index mark become evident as the students attempt to readjust the valve's stem position. If all is in order there will be no leaks when the pump is turned on, and the valve will close off almost completely or open to full capacity at appropriate settings of air pressure to the actuator. Both rigs have 500 L header tanks, and the pumps deliver up to 150 L/min through 50 mm pipes and fittings.

• *Process Pump* •

These rigs are similar to the above except that the focus is on the pump itself, and therefore manual butterfly or gate valves replace the control valves. The two, somewhat larger, centrifugal pumps are quite different from each other. One is designed for clean liquids and is a vertical mount design with shrouded impeller, mechanical seal, and seal flushing line. The other, a pump for mineral slurries, has an open, rubber-lined centrifugal impeller seal. Students dismantle the pumps as far as the sealing mechanisms which they draw in exploded diagrams. After reassembly, the pumps must operate without leaks, undue vibration, or other malfunction. A standard flowrate versus pressure curve is drawn for each rig, and students from the two groups compare the results, together with impeller diameters and rotational speeds. Students are also asked to describe the principle of the centrifugal pump and the concepts of "priming and cavitation."

Students measuring spacings of plates on the plate heat exchanger.

• Pressure Relief Valve •

The rig consists of a pair of similar 100 L compressed-air tanks connected by 25 mm piping with a ball valve. One tank is connected directly to the high-pressure main and can be filled with air to about 600 kPa. The second tank is equipped with a relief valve set just above the tank's nominal working pressure of 300 kPa. Students depressurize both tanks and dismantle the valve to display the disc, nozzle, and blowdown rings. After reassembly, the valve is recalibrated on a test stand equipped with a precision pressure gauge. It is then adjusted to give the correct "cold-set" pressure and is leak-tested before being returned to the main air tanks. To demonstrate the valve operation, students open the ball valve when the first tank if full of air (600 kPa) and the second is approximately half-full. They note the pressure when the valve first lifts (with a loud exhalation of air) and when it abruptly shuts again. After this they repeat the demonstration with a bursting disc and housing replacing the relief valve. Ear protection is used for this exercise, and a wire cage prevents any fragments from escaping. Students write short notes comparing the operation of the two types of safety equipment and describe the terms "accumulation" and "blowdown" as applied to the relief valve.

• Shell-and-Tube Condenser •

Two essentially similar shell-and-tube exchangers are equipped with condensing water flow meters and gauges for the inlet and outlet temperatures. Steam condenses on the shell side.

Students remove the head-pieces from the exchangers, exposing the internal view of the tube bundles. They note the construction material, the flow paths, and the tube diameters and lengths. They also make notes on the quality of the gasket and observe the correct order of tightening the many nuts on the circular head-piece. After reassembly, the rig is tested for leaks, and if all is well steam is put to the shell. At steady state, heat fluxes (as determined by flowrate and temperature rise of cooling water) are compared to the rate of condensate production. This heat balance shows the high efficiency of heat transfer from steam to water. Students then turn the cooling water flowrate down to a trickle and show that after a time the cooling water can be boiled, emerging as steam itself.

• Plate Heat Exchanger •

The rig consists of a circuit in which a viscous process fluid, molasses, is pumped from a tank via a steam-heated plate exchanger, then to a water-cooled plate exchanger, and finally back to the tank. A progressive-cavity pump, fitted with a variable-frequency speed controller, allows stepless and consistent flowrate changes. Students dismantle the plates of the steam-heated exchanger, observing the alternating pattern of gaskets which direct the flows of the respective fluids. After drawing the arrangement, they reassemble the exchanger, observing the correct sequence for tightening bolts—a key principle in the correct operation of this type of exchanger.

After reassembly, with cooling water flowing and molasses being pumped, steam is applied to the exchanger. If any leaks are evident, a time-consuming dismantling job must be done. Students finally determine the total duty of the exchangers, noting that the steam-heated exchanger has a far greater heat transfer coefficient than the water-cooled one.

• Steam Trap •

The process consists of a simple coil of copper pipe through which steam is passed to heat water in a 100 L tank. The condensate is passed to either of a pair of alternative steam traps: 1) a mechanical float-type trap, or 2) a thermostatic-type trap. Students first dismantle both traps and sketch the internal workings, noting the mode of operation and the materials of construction as well as removing and cleaning the strainer. After reassembly, they apply steam to the process and observe the rate of temperature rise, comparing the two types of steam traps for efficiency.

Heat balances are done by measuring the rate of condensate production compared to the rate of temperature-rise to show: 1) the steam is not 100% dry-saturated, and 2) that some of the heat is lost to the environment. Students are asked to describe the best steam trap for a range of particular purposes.

• Plate and Frame Filter •

A full-sized industrial filter is set up to separate a slurry of PVC resin in water. Students dismantle the filter rig and observe and sketch the internal arrangement of plates, frames, and filter cloths. They calculate the volumetric capacity of the unit for filter cake, and then prepare the process feed slurry in a tank with the appropriate amount of solids. During the filtration run, they measure the pressure drop across the filter and compare it to the rate of filtrate production. The students are asked to describe the significance of their data and to answer questions about constant-rate and constant-pressure batch filtration.

DISCUSSION

After just one semester, the laboratory has achieved a number of important educational goals. Because novel concepts are treated from the outset of the course, they make a strong impression on the students, leaving (we hope) an enduring notion of desirable engineering practice.

Students are exposed to a genuine chemical plant that performs an identifiable chemical process. Suppressing their initial anxiety, they applied themselves enthusiastically to the new tasks, learning the names of plant items, reading instruments, opening and closing valves, and recognizing the correct sequence of events for any operation. They get an idea of the scale of a chemical plant and the difference between it and the bench-type laboratory work that they encountered in high school.

The plate-and-frame filter press stands in as a workbench/desk prior to a run.

We emphasized industrial safety procedures. Before the work began, we presented a detailed talk on safety in the workplace, focusing on the hazards in a "hostile and unfamiliar" environment. We insisted on appropriate dress for the laboratory, consisting of an approved hard-hat, a long-sleeved boiler suit, steel-capped safety shoes, and safety glasses when required. We also employed a "permit-to-work" system prior to stripping a rig, and we constantly reinforced proper respect for sources of energy (steam, electricity, and compressed air). At least 25% of the assessment was on safety awareness and practice. Accidents as a result of poor practices would not only give the individual pain, but would also cause marks to be lost.

We developed logical and systematic investigation methods. In writing up laboratory notebooks, students were trained to describe a rig and its performance in unambiguous language. This exercised their ability to learn the names and functions of unfamiliar tools and equipment, to use precise technical descriptions, to become familiar with engineering units, and to state clearly what they observed. Students quickly became aware of the difference between an engineering report and that of a more traditional science laboratory.

A generous level of supervision helped greatly in running the sessions successfully. Students appreciated the immediate availability of demonstrators, and they responded by spending extra preparation time in drawing flowsheets and becoming familiar with the rigs. This allowed the prepared students to be unconcerned about the time remaining and to concentrate on understanding the equipment and the data.

Information transfer was handled by illuminated display boards and printed notes. Background reading relevant to each rig was noted permanently on display boards outside of the laboratory. These display boards were a constant reminder that information was always near at hand. To help guide students through the manual activities, they were given laboratory notes describing the experimental procedure in precise detail. This approach was greatly appreciated since most of the students had never used tools seriously before. Permanent copies of the notes for each rig were kept in the laboratory, and the students could purchase a set if they so desired.

The department at Sydney now has a high proportion of women students (30-40%), and when they first arrive many have the impression that they are disadvantaged with respect to men, whom they see as inherently more capable with machinery. However, it has been our experience that there is no observable difference between the performances of men and women when it comes to their facility with tools and equipment. All of the students enter the second semester with a much greater feeling of equality and confidence.

A novel aspect of the course was building the rigs themselves. Seeing the importance of the venture, our friends in industry agreed to construct rigs according to our specifications, but first we had to convince them that this would not be financially unattractive. Economies were realized by using "retired" equipment when possible, and by using apprentice labor augmented by some supervision and design by senior students. Donations of this type were welcomed as tax deductions. We approached all of our industrial donors simultaneously, which allowed us to commission the laboratory in just over one year from its conception.

We operated the laboratory in much the same way in 1990, but we commissioned two new experiments: 1) investigation of the performance of a simple level control rig using a pneumatic controller, and 2) investigation of the behaviour of an air compressor under variations in supply and delivery pressures. Both experiments involved a dismantling task followed by reassembly and operation

CONCLUSIONS

Over the last decade there has been a growing realization that engineering education has undergone an expansion of theoretical exercises at the expense of practical experience. Australian and British reports on the engineering profession together with the Institution of Chemical Engineering degree requirements,[1-3] reinforced the realization that there is a need for a field of training, called *Engineering Applications*, which would seek to correct the imbalance. We feel that this new laboratory makes significant progress in that respect.

In setting up the laboratory, one of our major intentions was to give students a close look at the profession that they have chosen. As a result, one or two students may make an early decision that chemical engineering is not for them, something that they might have taken several years to realize otherwise. The students who do remain now identify themselves as engineers with a developing set of theoretical and practical skills that distinguish them as worthy professionals. They also volunteer that while the experience was hard work, it was also fun.

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Our thanks also to the laboratory and technical staff of the department for their special effort in commissioning the laboratory. It has been named the "Chemical Engineering Foundation Laboratory for Engineering Applications" in recognition of the strong support of the Foundation in planning and liaison with our industrial donors, most of whom are members of the Foundation.

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