PROVIDING INDUSTRIAL EXPERIENCE IN A REGULAR LABORATORY COURSE

ROBIN A. CHAPLIN
University of New Brunswick • Fredericton, New Brunswick, Canada E3B 5A3

Industrial experience has always been considered an important part of the engineering curriculum at the University of New Brunswick. There are, however, limited facilities for students to obtain industrial experience. As a result, the university continually explores ways of providing the necessary exposure. The Department of Chemical Engineering has developed the following activities to achieve this end:

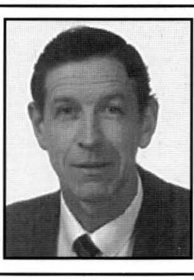
First Year	Factory Tours
Second Year	Boiler Test
Third Year	Practice School
Fourth Year	Plant Design

All of these activities form a part or the whole of required courses within the chemical engineering program, and academic credit is earned for the work. There is also a provision for students to obtain academic credit for summer research projects or work terms in industry, but since this is optional, it is not considered in this paper.

The main emphasis in this paper is on the boiler test, which I have directed on a number of occasions and have modified from time to time. I believe that it now provides good exposure to an industrial operation and that students learn a great deal from it. Most of all, they seem to enjoy it.

FACTORY TOURS

An effort has been made to introduce chemical engineering students to chemical engineering practice in their first year in the engineering program. The concept of factory tours was to stimulate interest in chemical engineering during the students' first year of study. The visits are carried out within the regular program and, as a follow-up exercise, students write an essay on the particular industry they visited. The essay also serves to assess the students' competency in English writing early in the program.



Robin Chaplin, *after some fifteen years of industrial experience, returned to university, obtained a PhD from Queen's University in 1986, and took the position as Chair in Power Plant Engineering at the University New Brunswick. He teaches thermodynamics and fluid mechanics, as well as specialized courses in nuclear and conventional power plants. At various times he has supervised the laboratory course referred to in this paper.*

BOILER TEST

Introduction • There is a heating plant that supplies heating steam to both the University of New Brunswick campus and the regional hospital. The heating plant, shown in Figure 1, has one wood-chip-burning boiler and two fuel-oil-fired boilers capable of generating 40,000 lb/hr (5 kg/s) and 120,000 lb/hr (15 kg/s) of steam each, respectively. Saturated steam for space heating is supplied at a pressure slightly above 200 lbf/in^2 (1.3 MPa), and the condensate is returned for preheating and feeding back into the boiler.

When I first became involved with the second-year chemical engineering laboratory course, I found that the boiler was treated as some kind of reactor on which a mass balance was carried out. Since redundant data were obtained, there was confusion as to how to close the mass balance. Due to errors in measurement, the mass balance never closed, leaving the students frustrated and confused since they did not yet have the depth of knowledge to sort out the conflicting results. Since then, I have made two changes: the first was to provide better direction on what was to be achieved, and the second was to ensure the students had adequate theoretical background to assess the results. The test is now done in accordance with the ASME Power Test Code for Steam Generating Units,[1] and the objective is to determine the boiler efficiency.

Course Structure • The second-year laboratory course runs for twelve weeks and comprises the boiler test (40%), fluid mechanics (40%), and industrial safety (20%). This breakdown is for assessment and grading purposes, but somewhat more laboratory time (about 50%) is actually spent on the boiler test. The fluid mechanics portion of the course encompasses execution of laboratory experiments and writing up laboratory reports. In this part of the course, students spend more of their own time writing up laboratory reports—hence the lesser amount of scheduled laboratory time. The industrial safety portion of the course includes lectures by industrial safety and fire protection officers from outside the university. The final examination in the course is biased towards safety aspects.

The boiler test itself occupies four lectures and seven laboratory sessions:

Lecture 1	Course structure and requirements
Lecture 2	Boiler configuration and efficiency
Lecture 3	Boiler test equipment and procedures
Lecture 4	Boiler test report and presentation
Laboratory 1	Thermodynamics tutorial
Laboratory 2	Heating plant tour
Laboratory 3	Test equipment check (two experiments)
Laboratory 4	Test equipment check (two experiments)
Laboratory 5	Boiler test at heating plant
Laboratory 6	Presentation of results
Laboratory 7	Mid-term test

There is one lecture and one laboratory session each week. The purpose of the lectures is to give direction to the whole class and to explain general principles applicable to the equipment to be used and procedures to be followed. The whole process may be explained by following the activities in the laboratory sessions and noting that the lectures simply provide a support function. Normally there are between 30 and 36 students in the class. The class meets as a whole for the lectures and divides into two teams of half that size for the laboratory sessions on different days.

Boiler Efficiency • The objective of the boiler test is to determine the efficiency of one of the fuel-oil-fired boilers, using the appropriate ASME Power Test Code. The efficiency is determined by the Input-Output Method and by the Heat-Loss Method. This requires measurement of the following parameters:

- Steam flow rate (direct reading)
- Steam quality (throttling calorimeter)
- Steam pressure (direct reading)
- Feedwater pressure (direct reading)
- Feedwater temperature (direct reading)
- Fuel-oil flow rate (direct reading)
- Fuel-oil calorific value (bomb calorimeter)
- Ambient air pressure (mercury barometer)
- Ambient air temperature (sling psychrometer)
- Ambient air humidity (sling psychrometer)
- Inlet air flow rate (Pitot tube traverse)
- Exhaust gas analysis (Orsat apparatus)
- Exhaust gas CO_2 (electronic probe)
- Exhaust gas temperature (electronic probe)
- Boiler wall temperature (thermocouple traverse)

Where direct readings are indicated, they are taken from existing instrumentation. Other readings are obtained from laboratory equipment or equipment temporarily installed for the boiler test.

In addition, operating conditions are monitored in case transients occur or there are losses from the system such as blowdown of boiler water. Corrections also have to be made to the direct readings to account for operation away from design conditions, *e.g.,* the effect of steam pressure on the steam flow calibration.

The efficiency by the Input-Output Method is

$$\eta = M_{steam}\Delta h / M_{fuel}CV_{fuel}$$

and the efficiency by the Heat-Loss Method is

$$\eta = (M_{fuel}CV_{fuel} - \text{Losses}) / M_{fuel}CV_{fuel}$$

where

M_{steam} = mass flow rate of steam
M_{fuel} = mass flow rate of fuel
CV_{fuel} = calorific value of fuel
Δh = enthalpy difference between steam and feedwater
Losses = heat loss in exhaust gas plus heat loss from boiler walls

The various steps in executing the whole process are described below.

Thermodynamics Tutorial • Students coming into the laboratory course have normally completed the first course in engineering thermodynamics. This course covers power cycles, steam systems, boiler efficiency, and combustion calculations, along with the basic concepts of heat and energy. In the thermodynamics tutorial, this knowledge is reinforced by having the students find the answers to problems such as:

- The power required to drive a feedwater pump given inlet and

Figure 1. *Heating plant.*

outlet conditions and flow

- The quality of steam in a steam line given data from a throttling calorimeter
- The efficiency of a boiler by the Input-Output Method, given steam and feedwater conditions and flow as well as fuel calorific value and flow
- The air-fuel ratio required for the combustion of a simple hydrocarbon fuel with specified excess air
- The air-fuel ratio for a simple hydrocarbon fuel given volumetric analysis of flue gas from an Orsat apparatus
- The efficiency of a boiler by the Heat-Loss Method given gas conditions and flow as well as fuel calorific value and flow

The problems demonstrate the basic calculations required to determine boiler efficiency and to give some meaning to subsequent work.

Heating Plant Tour • The next phase is a tour of the heating plant, conducted by the plant supervisor. Data related to the boilers and their operation are presented and the students subsequently have access to the plant and operators to fill in missing information. Before leaving the plant, they have to submit a layout diagram of the plant, a listing of technical data, and a written description of the plant and its operation. A minimum of direction is given to allow for individuality and initiative.

Test Equipment Check • This section occupies two laboratory sessions and requires the execution of four simple experiments (two each session) on the following pieces of laboratory equipment: the airflow rig, the bomb calorimeter, the heat-loss rig, and the Orsat apparatus.

The students are divided into four groups of about four students each. The groups rotate so that all students work on all pieces of equipment that will be used in carrying out the actual boiler test. The experiments are relatively simple since the main purpose is to allow the students to become familiar with the apparatus and to get hands-on experience. The work done of each piece of equipment is shown below.

Air-Flow Rig • Measurement of air flow emerging from a duct by doing a Pitot tube traverse • Measurement of humidity using a sling psychrometer • Measurement of atmospheric pressure on a mercury barometer

Bomb Calorimeter • Standardization of the calorimeter using benzoic acid pellets or the determination of the calorific value of a fuel oil

Heat-Loss Rig • Measurement of temperature at various points on a non-uniformly heated steel plate using a thermocouple probe • Determination of heat loss from the plate

Orsat Apparatus • Determination of the oxygen content of the air in the laboratory • Determination of the composition of a simulated flue gas

At this stage in their program, the students generally have not had exposure to the theory that supports these experiments. Most are just starting fluid mechanics and none have had heat transfer. The required background is therefore given in the laboratory manual—this is a good demonstration that useful work can be done by reference to appropriate material.

Boiler Test at Heating Plant • For the real test, the groups are slightly restructured from the original four groups to create five groups of about three students each. This is done by pulling out selected students who are judged to be able to adapt to the transition—usually the most senior in the class. Each of these new groups is then responsible for heating-plant measurements of 1) steam and fuel flow (new group), 2) combustion air flow, 3) fuel oil characteristics, 4) boiler heat losses, and 5) stack gas analysis.

The additional group (#1) must take measurements from the existing plant instrumentation as well as from a temporarily installed steam calorimeter. This is an area where the theoretical background has been covered and if the group has been well constituted, the students in that group come together easily. Their measurements are critical to the success of the whole exercise since the steam and fuel flows are key parameters. The other groups are by this time familiar with the equipment they are using and each group simply repeats one of the previous experiments, only on a larger or more rigorous scale.

The test is conducted over a period of two hours, with steam and fuel flows being read every 15 minutes and other measurements less frequently, depending on the constraints of the equipment.

Presentation of Results • A week later, the team as a whole has to present its results, with each group giving its analysis and each student giving his or her contribution. To do this, there must be some interchange of information and cooperative work between groups. Naturally, this does not always happen (some groups or individuals work in isolation), but it is a demonstration of the need to work as a team.

For the presentation, each student is required to prepare some overhead projector slides and to explain part of the proceedings. Each student is graded as follows:

Attendance	1
Overheads (visual impact)	3
Presentation (verbal logic)	3
Technical Content	3
TOTAL	10

The attendance mark is simply a bonus mark so that the others can be marked on a simple scale: 1, satisfactory; 2, good; 3, excellent.

Questions from the other groups and discussion between the groups is encouraged after each group's presentation. It also provides an opportunity for the laboratory supervisors to clarify misconceptions or explain deficiencies.

The presentation of results is followed up by a joint report from the team as a whole, with each group contributing one section of the report. The objective is to produce a single formal report in a consistent format where the efficiency of the boiler is calculated and presented. This is, in theory, an excellent exercise since it demonstrates what is required in industry. In practice, however, it falls short because not all students make an equal contribution and it is difficult to justify giving lower marks to those suspected of not doing their fair share.

Mid-Term Test • A mid-term test concludes this part of the course. Since the various groups have worked on different aspects of the boiler test, it is desirable to examine the students on their overall knowledge of boiler plant testing. As far as possible, the questions are directed toward the knowledge and experience that should have been gained by the exercises rather than factual information given in the laboratory manuals. The test includes both simple calculations and descriptive answers. Generally, the results in the most recent test appeared to be a fair reflection of the knowledge and ability of the students.

One aspect worth noting is that all work (except the formal report on the boiler test) has to have been done in laboratory books. The mid-term test is also done in the laboratory books—no supplementary references are permitted. It is, therefore, advantageous for the students to have well-documented records to refer to during the mid-term test. Another fact of interest is that, with separate teams on different days, separate and different mid-term tests have to be set. This challenges the instructor, who knows that even if the question sheets are collected after the first exam, there will be consultation between teams before the second exam.

Make-Up Assignments • Should a student miss a laboratory session for some valid reason, various makeup assignments are available. He or she is required to spend a period in the heating plant tracing out the pipelines of a selected system, such as the feedwater system or the oil system, and to develop a flow diagram for that system. The flow diagram must show all valves and fittings and instrumentation points so that it is evident how the system works. This work is self-paced, with no supervision—but the end result clearly shows the effort put into the exercise.

Conclusion • The boiler test provides students with exposure to the industrial world. They have the opportunity of working in an industrial setting, of talking to plant operators, and of generally finding out what industrial engineering is like. They are encouraged to spend as much time at the plant as they can afford and to make follow-up visits to learn more about the plant or to find missing data.

This part of the course demonstrates the need for fundamental theory and shows the practical application of the basic sciences. One student commented, "Some concepts were hard to grasp, but now that I have seen them applied, the material makes sense." It also shows the problems that can arise in practical engineering: "I felt that the experiments where I learned the most were the ones that went totally wrong."

Generally, comments from the students regarding the boiler test are good. The harder they have to work and the more effort they put into it, the more satisfaction they derive from it. Of course, the professor must ensure that the demands are not excessive and that the grading is done fairly so they are rewarded for their efforts.

PRACTICE SCHOOL

Practice School projects are conducted in industry by small groups of students. They take place over a two-week period in the spring, immediately after the final examinations. Each project is jointly supervised by a faculty member and an industrial engineer, and the students subsequently have to produce a report and give a formal presentation. It is part of the regular program and students obtain academic credit for it. Coordination is not easy, but each year the instructor[2] manages to match most students with the limited number of projects available.

PLANT DESIGN

Plant design projects are conducted during normal term time. Following identification of a real industrial problem, students work in groups to find alternative solutions. Regular meetings with the plant engineers and occasional visits to the industrial site are made to keep the project on track. At the conclusion, presentations are made, the solutions are discussed, and a report is submitted. This venture has proved to be very successful and of benefit both to the students and to the company.

CONCLUSION

While it is difficult to provide industrial exposure to students within a required university course, we have succeeded in doing it at the University of New Brunswick by using an industrial facility on the campus. Through appropriate organization, it is possible to give all second-year students some industrial experience early in their education as part of the regular chemical engineering curriculum.

ACKNOWLEDGMENTS

The author wishes to acknowledge the support and assistance received from Brian Lowry and Frank Collins in making the boiler test a meaningful exercise and in carrying the balance of the laboratory course to a successful conclusion. Nancy Mathis, of Mathis Instruments Ltd., initiated the original concept of factory tours; Mladen Eic coordinates the matching of students to practice-school projects each year; and Guido Bendrich directs the plant design projects.

REFERENCES

1. American Society of Mechanical Engineers, "ASME Power Test Code, Steam Generating Units," PTC 4.1 (1964)
2. Eic, M., "Practice School in the Chemical Engineering Curriculum at the university of New Brunswick," 42nd Canadian Chemical Engineering Conference, Toronto (1992) ❐