ChE department

UNIVERSITY OF ALBERTA

Tradition and Innovation

Chemical & Materials Engineering Building

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Chemical engineering has played a key role in the development of Canada's oil and gas and associated petrochemical industries, and chemical engineering at the University of Alberta (UofA) has been an integral part of the growth of the petrochemical industry in western Canada. The UofA is located in Edmonton, capital city of the Province of Alberta. The western part of the province is part of the majestic Canadian Rockies - The Continental Divide makes up a significant part of the western border between Alberta and British Columbia. The southeastern part of the province is part of the Canadian Prairies, while the north is part of Canada's extensive boreal forest. To the south, Alberta borders on Montana—Big Sky Country. Alberta also has a lot of "big sky"; there are more hours of sunshine per year than in any other part of Canada.

Oil and natural gas fields are found throughout the great sedimentary basin from the Alberta foothills in the west to the prairies in the east. Heavy oil and oil sand deposits, which contain more hydrocarbons than the Middle East, are located north and east of Edmonton. The discovery of oil in the 1940s and the beginning of large-scale commercial development of the oil sands in the 1970s had major impacts on chemical engineering education in Alberta. The evolution and current state of the chemical engineering program, with some gazing into the future, make up the heart of this article.

HISTORY

The UofA opened for classes in 1908, about three years after the western part of the Northwest Territories of Canada became the Province of Alberta. The UofA campus is located on the south bank of the North Saskatchewan River, which flows through the center of Edmonton. The first Annual Calendar of the university described this site on the riverbank, 200 feet above the river, as a "beautiful wooded park, which lends itself splendidly to an architectural scheme suitable for university purposes." Today the campus is surrounded by the city of 700,000 inhabitants. Despite the tremendous growth of Edmonton, the river valley that runs through the center of the city is largely an undeveloped, beautiful park. As the city has grown, so has UofA. The university's enrollment has grown from 45 students in 1908 to slightly over 30,000 in 1999.

Size of the chemical engineering classes has also grown from the first three graduates in 1928 (when chemical engineering was a special program in the Department of Chemistry) to between 65 and 70 Bachelor of Science degrees awarded annually for the last few years. Many other changes have occurred since 1928. In 1946, the department became one of the departments in the Faculty of Engineering, and in 1948, shortly after the discovery of a major oil field just south of Edmonton, it was renamed the Department of Chemical and Petroleum Engineering.

For the next 25 years, the department offered undergraduate and graduate programs in chemical and in petroleum engineering; it was also during this period that research began to be an increasingly important component of the department's activities. In 1973 the OPEC oil embargo precipitated an oil crisis, and the department again became the Department of Chemical Engineering when the petroleum engineering faculty members joined another department. In the late 1970s, a co-operative engineering program was introduced in which participants obtain 20 months of relevant industrial experience as part of the five-year undergraduate program. The majority of our chemical engineering undergraduate students are currently enrolled in the co-op program. The computer process control (CPC) program was introduced as an undergraduate elective stream in 1986 and the first students graduated from this unique program in 1989. (A more detailed history of our department can be found in Wanke[1] and Mather.[2])

The 1990s witnessed major changes. The department had 18 academic faculty members when the decade started, but by 1996 one-third of them had retired and been replaced and an additional two new positions had been created through expansion of the program. In addition, nine materials faculty joined the department, resulting in the first Department of Chemical and Materials Engineering in Canada. The influx of new staff brought with it excitement and new approaches to teaching and research in the department.

The changes and growth experienced in the 1990s were accompanied by significant growth in the numbers of undergraduate and graduate students. Each undergraduate engineering program has a quota in the sophomore year; the chemical engineering quota increased from 65 to 75 in 1996, to 90 in 1999, and will increase to 100 in 2001. About two-thirds of the chemical engineering

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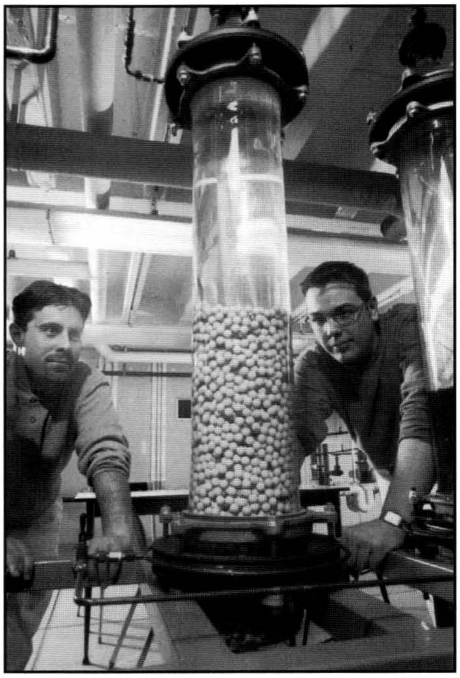
◄ Tina Barker in the departmental scanning electron microscopy laboratory.



Undergraduate student and instructor next to fluidized bed column. ►

sophomores completed their first year of engineering at the UofA; the remaining one-third are transfer students from junior colleges and transfers from other programs. A total of 299 undergraduate students are registered in chemical engineering in the 1999-2000 academic year. The number of graduate students has also increased significantly, from about 75 in 1996 to 110 in 1999; on the average, 40 to 45% of graduate students are PhD students and the remainder is enrolled in a variety of master's programs. The department also hosts a large number of postdoctoral fellows, research associates, and visiting faculty; currently 29 postdoctoral fellows, 22 research associates, and 5 visiting professors reside in the department.

> ***Teaching chemical principles with applications to Alberta's industries is one of the main functions of the department, and undergraduate students can choose from a variety of program and delivery options.***

The current academic staff consists of 24 chemical engineering and 10 materials engineering faculty; 16 of these 34 have been hired within the past five years, and there are four academic vacancies to be filled within the next three years. The department also employs 20 permanent support staff: three machinists and two electronics technicians who run the departmental machine and instrument shops and custom-build and repair equipment for undergraduate and research laboratories; two computing and network specialists who keep the computing, data acquisition, and network systems functioning; four laboratory technologists who assist with the undergraduate laboratories and operate special facilities such as the departmental scanning electron microscope; and the remaining support staff provide the clerical and administrative support necessary for smooth operation of the department.

The staff, graduate students, researchers, and some of the classrooms are housed in the Chemical and Materials Engineering Building. This 8-story, 184,000-ft^2 building was built in 1968, and currently over 80% of its space is occupied by the Department of Chemical and Materials Engineering, which will be the sole occupant of the building after an Electrical and Computer Engineering Research Facility is completed in 2001. Although the building is over thirty years old, it has been well maintained and the laboratory space is of excellent quality. Much of the large-scale separation equipment and high-pressure reactor facilities were constructed in the departmental machine and instrument shops. These two shops, along with the interfacing expertise of our computer staff, have contributed significantly to the success of our experimental research programs.

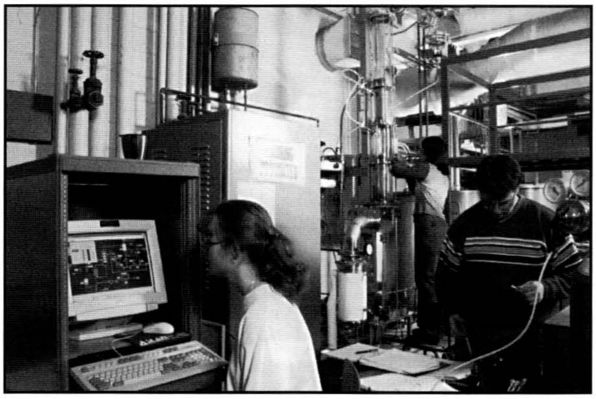
PROGRAMS

Teaching chemical engineering principles with applications to Alberta's industries is one of the main functions of the department, and undergraduate students can choose from a variety of program and delivery options. Three degrees are offered: a BSc in Chemical Engineering, Chemical Engineering (Computer Process Control), and Materials Engineering—all of which can be completed in the traditional mode (eight academic semesters) or the co-operative education program (eight academic semesters plus twenty months of engineering work experience interspersed with the academic terms). Approximately one-third of the students are pursuing the regular route to their engineering degree and two-thirds are pursuing the co-operative route. All the programs are accredited by the Canadian Engineering Accreditation Board.

Undergraduate students usually enter the chemical engineering programs after a common first year of study, summarized in Table 1. First-year engineering students are placed in specific programs of study according to a quota for each program, based on their indicated preferences and grades. In March of each year, the first-year engineering students select three programs of study in which they are interested, ranking their choices in order of preference. Then, based on each student's GPA and the quota for the various programs, the Faculty of Engineering assigns students to specific programs of study. The yearly entrance quotas for the chemical engineering programs currently total 90 students and will be expanding to 100 students within the next two years. Of the approximately 90 students per year that have been admitted to chemical engineering programs during the last several years, almost all have indicated chemical engineering as their "first" choice.

As shown in Table 2, the traditional chemical engineering program is similar to many programs across North America. The key exception is the emphasis placed on both chemical engineering laboratories and process design. The chemical engineering laboratories consist of three separate courses, which serve the dual purposes of providing the students with hands-on experience with pilot-scale chemical engineering processes (*e.g.,* heat exchangers, distillation columns, fluidized bed systems, etc.) and report writing. The design stream includes courses in engineering economics and finance, as well as two single-semester process design courses. The engineering economics and first design course provide each student with a solid foundation to complete the second design course, which is project based. In this final design course, each student group, involving three or four students, chooses a separate design project drawn from local industries.

The CPC program is a blend of chemical engineering



▲ *Undergraduate students doing the senior distillation laboratory.*

TABLE 1
Common First-Year Engineering Curriculum

Subject Area	*Single Semester Course Equivalents*
Chemistry	2
Physics	3
Mathematics	3
Computing	1
Humanities	1
Other	0.67

▼ *Dr. Suzanne Kresta and students in a problem-solving lab.*

TABLE 2
Chemical Engineering Curricula Beyond the First Year

Subject Area	ChE*	CPC**
Chemistry	2	1
Mathematics, Statistics, Numerical Methods	5	5
Thermodynamics	3	2
Transport Phenomena	4	4
Reactor Design and Analysis	1	1
Process Design, Analysis, and Economics	4	4
Chemical Engineering Laboratory	3	2
Process Control	1	4
Materials Science	1	1
Electrical Engineering Fundamentals	1	2
Technical Electives	4	4
Communications (oral and written)	1.67	1.67
Humanities	3	3
Other	0.67	0.67

* *Chemical Engineering: figures given as single-semester course equivalents.*
** *Computer Process Control: figures given as single-semester course equivalents.*

fundamentals, specialty process-control courses, and components from electrical engineering and computing science. Wood[3] provides a historical perspective on the program as well as details of the development and design of the program. In 1999, the CPC program was modified to create two streams: computing systems and signal processing. The two streams are defined by technical-elective packages. In the computing-systems stream, students take electrical engineering courses in digital logic and microprocessors, a second computing science course, and a further technical elective. In the signal-processing stream, students take an additional mathematics course in complex variable theory, the electrical engineering signal-processing course, a second computing science course, and a further technical elective. Thus, the CPC program uniquely positions students to fill a niche in the process industries.

At the graduate level, Master of Science (MSc), Master of Engineering (MEng), and Doctor of Philosophy (PhD) degrees in three disciplines (Chemical Engineering, Process Control, and Materials Engineering) are offered. The MSc and PhD degrees are research-based and require that a student take six graduate-level, single-semester courses for the MSc degree and nine graduate-level, single-semester courses for a PhD degree. Of these courses, three must be selected from a core program, with the remainder being chosen to suit the student's interests. Since these degrees are research-based, each student must also complete a thesis. At the PhD level, students must complete three written preliminary examinations taking three hours each (usually after the first eight months of the program) and a candidacy examination of the proposed research and the student's capability to pursue the proposed research. The MEng degree is course-based and requires completion of ten graduate-level, single-semester courses as well as a project. The MEng is considered to be a terminal degree and not a route to the PhD program.

Recently, at the graduate level, a number of joint degree programs have been evolving. The two programs currently in place are Chemical Engineering and Medical Sciences, and Chemical Engineering and Biological Sciences. Coursework includes core chemical engineering courses, courses taken from the "partner" discipline, and courses that match the student's interests. These joint degree programs are new to the UofA, but student interest is driving their development.

One of the strengths of the UofA programs is interaction with industry. This interaction occurs formally through some unique programs and research projects, and informally due to the diverse set of industries in the Edmonton area. The program that has the largest single impact on ensuring industrial interaction with the undergraduate students is the Stollery Executive-in-Residence program. It is used to bring practicing engineers from a variety of industries into the department to provide guidance to student groups working on their design projects; it usually requires a commitment of approximately two weeks of the practicing engineer's time, spread over an academic term. Further, the Stollery visitors usually bring design projects from their own companies with them. The visiting engineers are also invited to give special lectures in other courses, where they provide context for the course subject matter.

At the graduate level, a large and growing number of research projects enjoy the partnership of local companies. These often require graduate students to spend extended stretches of time in company labs or at plant sites. This trend toward industrial participation in the training of graduate students seems to be of interest to local industries and is expected to expand.

RESEARCH

The second main function of the department is research, which has focused on adding to the chemical engineering knowledge base and addressing problems of the process industries, with particular emphasis on Western Canadian industries. The oil and gas industries in Western Canada strongly influenced the areas of research in the department during the 1950s and 1960s. Establishment of world-scale petrochemical facilities in Alberta in the 1970s and 1980s influenced the direction of applied research, and the increasing importance of the synthetic crude production in the 1980s and 1990s opened up exciting new areas for application of chemical engineering fundamentals. Construction of modern pulp mills and newsprint facilities in the 1990s added another dimension to the department's applied research.

Funding for research comes from external sources: in the 1998-99 fiscal year, funding obtained by the academic staff, excluding central overhead charges, exceeded $4.5 million (Cdn); about 65% of the funds came from federal and provincial government agencies, and the remaining 35% came from industry. Five of the main areas of chemical engineering research are briefly described below.

Catalytic Reaction Engineering • Catalysis and reaction engineering research has been done in the department since the 1950s when investigation of selective hydrocarbon oxidation and Claus catalysis were started. Claus catalysis for the conversion of hydrogen sulfide to elemental sulfur is still of great importance since most of Alberta's natural gas contains hydrogen sulfide. These studies not only resulted in significant improvements in sulfur recovery, but also resulted in the development of techniques (such as infrared methods) for examination of fundamental processes occurring on the surfaces of heterogeneous catalysts. Understanding the behavior of these catalysts led to the application of hydrophobic supported metal catalysts, which are finding applications in new processes such as the production of hydrogen peroxide and for the removal of organic compounds from contaminated aqueous streams. These catalysts are also well suited for catalytic distillation for water-containing systems. Current catalytic reaction engineering projects include: catalysts for environmental applications (both liquid and air), development of catalytic distillation processes, heavy-oil upgrading catalysts, and olefin polymerization catalysts (Ziegler-Natta and single-site catalysts). Departmental facilities for catalytic studies include various catalyst characterization equipment (chemisorption and physisorption, x-ray diffraction, scanning electron and atomic force microscopies, and infrared spectroscopy) as well as numerous reactors, including a continuous high-pressure system for studying hydrocracking of bitumen and a reactor system for catalytic olefin polymerization in the gas phase.

Computer Process Control • With the establishment of the Data Acquisition and Control and Simulation (DACS) Centre in the department in 1968, research in computer process control became one of the main research areas in the department. Each one of the many workstations in the center today has much more computational power than the IBM 1800 housed in the original DACS Centre, but the general aim of today's research is the same as that of three decades ago (*i.e.,* development of techniques that allow computers to be used for improving the efficiency and reliability of industrial process operations). Research areas have broadened over the years from the more traditional process control and identification to include process monitoring and the application of multivariate statistics, controller-performance assessment, artificial intelligence, process-fault diagnosis, and process optimization. The size of the process-control research group has grown commensurate with the broadening of the research scope. The computer process-control research facilities include a network of computers (Unix workstations and personal computers) and experimental equipment, including pilot-scale reactors, distillation columns, and other small experiments.

Fluid Mechanics and Transport Phenomena • The study of multiphase flow and flow in porous media, with emphasis on oil pipe lines and crude oil reservoirs, were major topics of research in the department from the 1940s to the 1970s. In the 1970s and subsequent decades, research shifted to experimentation and modeling of complex flows with applications to the transport processes encountered in the processing of oil sands. The work included modeling of complex processes used in the extraction of bitumen from sand, as well as experimentation necessary to increase understanding of the chemistry and physics that govern the processes in the liberation of the bitumen from the surface of the sand and subsequent processing of the bitumen. Research in this area contributed significantly to the improvement of commercial processes for the economic production of synthetic crude from the Alberta oil sands. Syncrude Canada Ltd., the largest producer of synthetic crude (225,000 bbls per day in 1999) has recognized these major contributions and co-sponsors, with the Natural Science and Engineering Research Council of Canada) two industrial research chairs in the department. Research in this area is moving from the continuum to the molecular level. Current projects include measurement of interfacial properties of individual drops in emulsions, interactions between bitumen droplets using a microcollider apparatus, and stabilization of bitumen-in-water emulsions by clays. Other active projects in this area include fluid dynamics aspects of pulp and paper processing and computational (CFD) and experimental studies in the area of mixing and separation equipment optimization.

Thermodynamics and Separation Technologies • Thermodynamics research, largely dealing with vapor-liquid equilibrium of systems related to oil and natural gas, started in the 1940s. It culminated in the 1970s with the publication of the Peng-Robinson equation of state. The separation research in these decades emphasized the measurement of data and modeling of systems used in the removal of hydrogen sulfide and carbon dioxide from natural gas. The process models developed for the sour-gas separation units and the vapor-liquid equilibrium data obtained for the amine-sour gas systems are still used today. In the 1980s, separation research shifted to improving the energy efficiency of packed and trayed columns. Fundamental work on factors affecting the efficiency of separation columns, including studies in interfacial properties, resulted in the development of column packings and column internals with improved efficiencies. These improvements are being used commercially. Current work is using the vastly increased power of computational fluid-dynamics (CFD) packages to model the influence of packing geometry on detailed flow patterns, with the aim of improving separation efficiencies. Distillation and packed towers, with one-foot diameters, are used to validate the CFD predictions. Research projects in thermodynamics today deal with the application of statistical rate theory to interfacial and membrane transport, experimental and molecular simulations of miscibility of polymer blends, and measurement of hydrocarbon solubility in polymers.

Advanced Materials • This is the most recent general area of research in the department. It started in the 1980s with an industrial-sponsored project on gas-phase olefin polymerization; the use of new catalysts to produce polyolefins with novel molecular architecture continues to be an active research area. Investigation into the thermorheological properties and microphase separation in block copolymers is ongoing. The preparation of magnetic microparticles with different surface functionalities is being studied; such particles have wide application in removal of contaminants from industrial effluents, carriers for drug delivery, and biological cell separation. The merger with materials engineering in 1996 brought many projects in advanced materials into our department, including surface modifications for improved wear resistance, preparation of electronic materials, and sintering of cemented tungsten carbide.

Other Research Activities • Academic staff participates in various formal interdisciplinary projects beside the chemical-materials projects; these include projects with the Departments of Biological Sciences, Chemistry, Civil and Environmental Engineering, Electrical and Computer Engineering, Mathematics, and Mechanical Engineering. Graduate students, who will receive double major degrees as described previously, are involved in several of these interdisciplinary projects. There are also joint research projects with other Canadian universities as well as with universities in China, Germany, Great Britain, New Zealand, Poland, Taiwan, and Thailand.

THE FUTURE

Chemical engineering continues to change, and the programs at the UofA are no exception. The huge increases in computing and networking systems will affect the delivery of undergraduate and graduate programs and influence theoretical, modeling, and experimental research. Increasingly powerful and reliable design packages will reduce the amount of instruction dealing with empirical information, *e.g.,* property and transport correlations. The efficiencies provided by improved software and computing systems will be used to include more instruction on interfacial and molecular processes (*e.g.,* molecular phenomena important in colloidal suspensions, emulsions, and adsorption).

This return to the fundamentals of chemical engineering and applied chemistry is needed if our students are to play a major role in the burgeoning oil-sands industry. The increased reliance in Canada on synthetic crude oil, up to 50% of Canada's oil use of 2010, will require chemical engineers with a sound knowledge base in interfacial science (*e.g.,* the molecular processes involved in removal of high molar mass hydrocarbons from sand, the processes involved in the economic removal of solids from "stable" colloidal solids in process water suspensions, and the removal of corrosive materials present in submicron suspensions or emulsions). The revised curriculum should also reflect the changes in process control tools available today (*e.g.,* dynamic process simulation software, computer-aided mathematics packages, robust-optimization packages, etc.).

The applied research in the department will continue to focus on the main industrial activity in Alberta; the oil-sands (synthetic crude oil) industry, the petrochemical industries, and the pulp-and-paper industry. These industries will continue to be the core of Alberta's process industry for many decades, and the problems to be solved will be a continuing challenge to the university. The increased capabilities of available analytical, instrumental, and computational tools will allow solution of previously intractable problems; however, the basic principles of science and mathematics are still applicable to these problems. Departmental research will concentrate on the application of fundamental science and mathematics to the solution of practical problems and the development of new tools and techniques to solve these problems. Application of surface-science principles to the process industries, and the development of mathematical and analytical tools for improved process performance and materials characterization, will be the focus of our research in the next decade.

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