POSTGRADUATE ENVIRONMENTAL ENGINEERING PROGRAM
in the Department of Chemical Engineering at the National University of Singapore

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During the past three decades, there has been rapid industrial and economic development in East Asia and Southeast Asia. This development has now reached the stage where it is imperative for nations in the region to begin serious and concerted efforts to protect the environment. The environmental issues in these regions are deemed sufficiently important to have warranted special coverage in *Environmental Science and Technology*.[1]

Efforts to address environmental concerns in Singapore not only include new legislation and strict enforcement of laws and regulations resulting from the legislation, but they also cover a wide variety of activities and programs, including education and training of skilled manpower in environmental science and engineering, promotion of research and development work in relevant disciplines, and manufacturing and production of devices, products, and software that are important to protect and preserve the environment.

The interests and activities aimed at environmental protection have also had the effect of creating significant opportunities for manufacturing interests. The National Science and Technology Board (NSTB) of Singapore estimates that over the next five years, Asian countries will be spending $10 billion annually on environmental equipment, systems, and services. In line with this development, NSTB has designated environmental technology as one of the key technologies for Singapore's economic development of the next decade and has set up an Environmental Technology Institute to help propel Singapore's environmental technology industry to a higher level of competitiveness.

In its educational functions, the National University of Singapore (NUS) has long recognized the relevance and importance of the environment. Teaching and research activities dealing with various aspects of the environment can be found in many of its academic units. In view of the heightened interest in environmental technology, the University established a formal program in environmental engineering in 1995 at the postgraduate level, which was followed by an undergraduate program in 1997.

Before describing the features of this postgraduate program, it may be useful to highlight the rationale for launching an environmental engineering program at the postgraduate level with the Department of Chemical Engineering as its academic home. The program was designed to be a coursework-centered program that allowed candidates to build on their prior educational background and to acquire skills for the solution of advanced environmental engineering problems. It had to be sufficiently flexible to accommodate stu-

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dents from different backgrounds and to provide practicing engineers with an opportunity to upgrade and enhance their technical qualification, enabling them to participate and contribute to Singapore's push to develop an environmentally based industry.

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TABLE 1
Course Requirements for Postgraduate Diploma and MSc Degree

	Option 1	*Option 2*
Postgraduate Diploma	4 Foundation Subjects *plus* 4 Elective Subjects	4 Foundation Subjects *plus* 2 Elective Subjects *plus* Minor Project
Master of Science Degree	4 Foundation Subjects *plus* 6 Elective Subjects	4 Foundation Subjects *plus* 2 Elective Subjects *plus* Major Project

Historically, environmental engineering has been linked to civil engineering (or its sub-specialty, sanitary engineering), reflecting the early need for water and wastewater treatment. But many of the tasks facing environmental engineers in the developing Asian countries are extremely diverse and go far beyond the traditional "end-of-the-pipe" approach. Additional programs to complement the sanitary engineering approach were needed; programs that covered areas such as process modification and waste minimization to avoid pollution problems, environmental chemistry and microbiology, and transport processes.[2] These topics fit more easily into a chemical engineering program, with its emphasis on industrial process design and on chemistry, than into a civil engineering program; therefore the environmental engineering program is based in the Chemical Engineering Department at NUS.

COURSE STRUCTURE

In establishing the environmental engineering program, we were cognizant of the fact that environmental engineering is a multidisciplinary subject of study and that the program must be accessible to candidates with varied educational and professional backgrounds. We established a two-tiered program that offers either a Postgraduate Diploma or a Master of Science (MSc) degree, and which can be pursued on either a full-time or a part-time basis.

In order to be considered for admission into the program, applicants must at least possess a Bachelor's degree in science or engineering. Generally, the selection is based on the applicant's undergraduate academic record and the relevancy of his/her work experience (if any). Students may also be required to undergo an interview. The selection process for the MSc applicants is more stringent than for the Diploma applicants. Postgraduate Diploma students who have performed well may upgrade to the MSc program.

The course requirements for the program are given in Table 1. The foundation subjects are the more fundamental subjects and serve as a mechanism for filling in gaps in the background of the students from a variety of disciplines who are attracted to this program. Up to two of these foundation subjects may be waived for students who have demonstrated proficiency in these areas, with elective subjects replacing them. The elective subjects are the more specialized subjects and are further divided into two groups: Group 1 includes courses on advanced engineering science relevant to environmental engineering, and processes and devices used in pollution control and abatement; Group 2 covers more diverse topics such as risk, impact assessment, and other courses related to environmental engineering that are offered in the postgraduate chemical and civil engineering programs.

For the MSc environmental engineering students, under Option 1 at least three of the elective subjects must be from Group 1, while under Option 2, at least one elective subject must be from Group 1. For the Postgraduate Diploma students, the corresponding number of subjects from Group 1 are two and one, respectively. The project option (in lieu of four subjects for MSc students and two subjects for Postgraduate Diploma students) gives the students an opportunity to conduct research related to their interests.

The classes are conducted from 5:30 pm to 8:30 pm, giving practicing engineers and technologists an opportunity to upgrade and enhance their technical qualifications. Each semester lasts thirteen weeks. Up to 40% of the final grade may be based on continuous assessment, which comprises homework, quizzes, term papers, etc., with the final examination accounting for the balance.

COURSE CONTENT

The list of subjects offered in the postgraduate environmental engineering program are given in Table 2. The foundation subjects are formulated to meet the challenge of teaching advanced topics in environmental engineering to students with different backgrounds. Many of the students are practicing engineers/technologists who may have some relevant practical experience, but who are lacking in the fundamentals. The foundation courses are briefly described in Table 3.

The students are strongly encouraged to take the foundation subjects in the early part of their candidature before embarking on the more specialized electives. Some Group 1 electives (Aquatic Chemistry, Atmospheric Chemistry, and Biological Waste Treatment) require background knowledge covered in the Basic Environmental Science foundation subject. In the three remaining Group 1 electives (Water Pollution Control Technology, Air Pollution Control Technology, and Solid Waste Management), the students are assumed to possess sufficient knowledge of mathematical and engineering principles to understand the basic theory and unit operations of the treatment processes covered in these electives. For example, in Air Pollution Control Technology, the basic designs of the various control equipment for particulates (cyclone, venturi scrubber, etc.) and gaseous pollutants (scrubbers, packed bed adsorbers, catalytic reactors, etc.) are studied. In these electives, the philosophy that the best method of pollution control is the minimization of pollutant formation is also emphasized. For example, on the topic of the control of NO_x emission, the various mechanisms of NO_x formation during combustion and the factors affecting the formation processes are highlighted. The use of combustion technologies such as flue gas recirculation, off-stoichiometric or stage combustion to reduce NO_x formation are discussed in addition to the post-combustion control technologies that rely on the introduction of reactants to destroy the NO_x in the flue gas.[3-5]

The Group 2 electives (Table 2) provide the students with an opportunity to acquire more in-depth knowledge on chemical engineering topics such as reaction engineering, separation technology, process control, and modeling, as well as topics more closely related to civil and sanitary engineering. In addition, two electives, Quantified Risk Analysis and Environmental Impact Assessment and Auditing, highlight issues of current interest and importance. In Quantified Risk Analysis, the major hazard control legislations, practices and policies, hazard identification techniques and evaluations, risk assessment, and various dispersion and explosion models are covered. The Environmental Impact Assessment and Auditing elective covers impact analysis of land use and erosion, noise, air and water quality, vegetation and wildlife, as well as socio-economic and geological impact analysis and environmental

TABLE 2
Subjects in the Postgraduate Environmental Engineering Program

Foundation Subjects
- Basic Environmental Sciences
- Mathematical Methods for Environmental Engineering
- Physical Principles of Environmental Engineering
- Process Engineering Design Principles

Elective Subjects

Group 1
- Aquatic Chemistry
- Water Pollution Control Technology
- Atmospheric Chemistry
- Air Pollution Control Technology
- Biological Waste Treatment
- Solid Waste Management

Group 2
- Chemical and Biochemical Reaction Engineering
- Instrumentation and Process Control
- Quantified Risk Analysis
- Environmental Impact Assessment and Auditing

Subjects	
• Membrane Separation Technology • Advanced Separation Processes • Principles of Adsorption and Adsorption Processes • Advanced Reaction Engineering • Process Modeling and Optimization	Offered in the Chemical Engineering Postgraduate Program
• Water Quality Management • Industrial Wastewater Control • Toxic and Hazardous Waste Management • Advanced Hydraulics • Water Resource Systems Analysis • Environmental Health Engineering • Urban Environmental Management	Offered in the Civil Engineering Postgraduate Program

TABLE 3
Brief Descriptions of Foundation Subjects

Basic Environmental Science
Basic environmental chemistry, including concepts from general and physical chemistry, organic chemistry, and biochemistry • Fundamentals of environmental microbiology, including microbiological principles and biogeochemical cycles • Illustrations from water and wastewater treatment.

Mathematical Methods for Environmental Engineering
Linear algebra • Solution of systems of linear and non-linear equations • Numerical solution of initial value and boundary value ordinary differential equations • Parameter estimation and regression analysis • Introduction to optimization techniques • Statistical methods for process analysis • Examples and applications.

Physical Principles of Environmental Engineering
Fundamentals and applications of mass, momentum, and heat transport in environmental engineering • Advection, diffusion, dispersion, settling, and surface transfer in air and water • Applications in natural environment and treatment systems • Quantitative applications.

Process Engineering Design Principles
Introduction and classification of processes • Steps in process design • Material balances involving phase equilibria, chemical reaction, and recycle • Design of simple stagewise processes • Energy balances • Introduction to and use of flowsheeting packages.

auditing. In addition, ISO 14000 issues are also covered in this elective.

Currently, only a minority of the students take up the project option, since most of the students who are working full-time have difficulty conducting a project (especially an experimental one) and meeting with the staff members during office hours. Some examples of the MSc projects currently in progress are shown in Table 4.

TABLE 4
Examples of MSc Projects

- Measurement of Chemical Species in Rain Water
- Synthesis of Spinel Oxides for N_2O Decomposition
- Long-term Stability of Treated Lead-Contaminated Soil
- Nutrient Removal from Domestic Sewage Using a Modified Sequential Batch Reactor
- Enzyme Mimic Catalysis : Decomposition of Pollutants in Wastewater Treatment
- Modeling for the Prediction of Flue Gas H_2S/SO_2

TABLE 5
Students' Choice of Candidature

Postgraduate Diploma		*Master of Science Degree*	
Part-Time	Full-Time	Part-Time	Full-Time
26	7	69	8
33		77	

TABLE 6
Students' Educational Background and Working Experience

First Degree	
Science	45
Engineering	65
Working Experience	
(a) Number of Years	
<1	13
1-3	28
4-6	16
>6	53
(b) Employment Category	
Petroleum/Petrochemicals	11
Specialty Chemicals/Pharmaceuticals	12
Project Engineering/Construction	18
Environmental Services	9
Electronics	8
Commercial Laboratories	6
Government/Statutory Board	21
Foreign Companies	6
Not Employed/Fresh Graduates	8
Others	11

As illustrated by the projects in Table 4, there is a strong chemistry/chemical engineering component in these projects. The projects in the postgraduate program are supervised by staff from the Chemical Engineering Department (which include both chemical engineering and environmental engineering staff), Civil Engineering Department, and the Department of Microbiology.

STUDENT STATISTICS

The majority of the students in the environmental engineering program are practicing professionals who enrolled in the program on a part-time basis (see Table 5). About 60% of the students possess a Bachelor's degree in engineering, with the remaining having a degree in science (see Table 6). Few of the students embark on the postgraduate program directly after their first degree. About half of the students have more than six years of working experience and had worked in a wide range of sectors reflecting the industries in Singapore. There are a few foreign students (under the categories "Foreign Companies" and "Not Employed/Fresh Graduates"), mainly from Indonesia, Myanmar, India, and China. So far, thirteen students have graduated from this program; five of them were full-time students while the remainder were enrolled on a part-time basis. These full-time students found employment upon graduation in environmental consulting and engineering companies. The part-time students continued with their jobs upon graduation.

SUMMARY

At the National University of Singapore, the choice of the Department of Chemical Engineering to host the environmental engineering program reflects our philosophy that environmental engineers need knowledge of process engineering principles and applications as well as chemistry and microbiology. Since the establishment of the postgraduate environmental engineering program in 1995, thirteen students have graduated and 110 students are currently enrolled. The program is sufficiently flexible to accommodate students with varied backgrounds due to its unique features: a two-tiered (Postgraduate Diploma, MSc) program that can be pursued on either a full-time or a part-time basis and the provision of foundation courses to make up for any deficiencies in the students' background.

The rapid growth of this program and its popularity among working professionals demonstrate that there is a growing and previously unmet need for environmental engineering training in Singapore. In view of the success of the postgraduate program, the department has launched an undergraduate degree program in environmental engineering and the first students will graduate in the year 2000. The under-

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substantially complicate the design and tuning of the actual control loops. In general, the laboratory experiments provide students with valuable experience with physical systems and give them much needed practice in applying theory to the real process.

The distributed control system in our laboratory creates a dynamic environment in which control experiments are constantly evolving. The incremental improvements and the addition of new equipment (see Table 1) are accompanied by long-term projects aimed at increasing the functionality and availability of the experiments. The most important enhancement that we are currently working on will allow the instructors to run experiments online from the classroom using the standard Ethernet connection to the controller or the control server. Ideally, we would like to see not only professors running experiments remotely, but also students accessing the system from campus computer laboratories and their homes to collect the necessary data for their homework assignments or the design projects.

In the future we plan to make our laboratory available for the distant-learning students and for those using the Internet. Our initial experience (during the first remote demonstration of one of our control experiments,[8] the unattended control laboratory was flooded), however, shows that before the system can be made available to the students and the outside world, the security of the systems must be substantially improved and the equipment must be modified to make it fool- and foul-play-proof before making it available for unsupervised remote experimentation. Despite potential problems, we see enhanced networking as a way to maximize the positive effect that the control experiments have on the educational experience of our students.

In addition to the effect on control courses, we are also witnessing a positive impact on research in process control theory since practical implementation of the theoretical results can be quickly and easily achieved. With the creation of the Teaching Center for Advanced Control Technology (TCACT), we are now in a position to enhance cooperation with industry by providing flexible and customized training of engineering and technical personnel in practical methods of modern process control using our laboratory.

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graduate program is motivated by the need to provide qualified engineers to address the environmental challenges associated with the large petroleum refining and chemical industrial base in Singapore. With the establishment of the environmental engineering program, the Department is the sole institution responsible for the training of both professional chemical engineers and environmental engineers in Singapore. To better reflect our academic and research programs in environmental engineering, the department has been renamed the Department of Chemical and Environmental Engineering, effective July 1998.

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