A Review of Fuel Science and Engineering Courses at MIT, the University of Sheffield and the University of Leeds, England.

Malcolm T. Jacques and J. M. Beer

The Energy Laboratory and Department of Chemical Engineering,
MIT, Cambridge, Ma. 02139

Introduction

Traditionally Fuel Science and Engineering has been regarded, from an educational viewpoint, as something of a hybrid subject which cannot be easily accommodated within the accepted framework of separate academic disciplines. In general faculties of science tend to treat the subject as an extension of Physical and Organic Chemistry with considerable emphasis on basic fuel properties and the chemistry of combustion. Engineering faculties on the other hand often provide courses in both Mechanical and Chemical Engineering Departments which concentrate on specific areas of fuel utilization and processing. Courses in Mechanical Engineering Departments deal mainly with only the physical and thermodynamic aspects of the combustion of fuels in F. C. engines and gas turbines. Chemical Engineering Departments in general do not provide specific courses on Fuels but do include a considerable amount of basic material relevant to the Fuel Processing area in several standard Chemical Engineering courses. Consequently it is the exception rather than the rule to find well-balanced schemes of study in the areas of Fuel Science and Engineering. Very few academic institutions provide a broad-based education in all aspects of fuels ranging from resources and recovery through to utilization and pollution control.

The current wave of interest and concern in all matters relating to the national energy situation provides sufficient justification for closely examining the educational programs of the scientists and engineers who will be needed to meet the demands in this area. It would be somewhat ironic if the new technologies and industries proposed to overcome the nations fuel supply problems were themselves subjected to a supply problem of adequately trained personnel. The question of whether or not our educational institutions currently provide appropriate programs for the number of personnel required in this area, still remains open. It is perhaps worth noting that several large American companies are currently recruiting graduate-level fuel scientists and engineers directly from U.K. Universities. Also it appears inevitable that as we turn to progressively more difficult fuels, the environmentally acceptable extraction, processing and utilization will lead to an increased requirement for professionals at all levels in the fuel and energy sector. A satisfactory answer to the questions raised here can of course only be obtained by conducting a detailed market survey of both the sources of supply of and demand for fuel scientists and engineers at both graduate and undergraduate levels. It is in this area that the professional societies could play an important role.

It is not the objective of this paper to provide answers to these questions of supply and demand, nor to address the more fundamental questions relating to the role of universities in regulating or controlling the supply in the interests of particular professions. Based on the premise that some changes may be desirable to improve either or both the quality and quantity of Fuel Science and Engineering courses, three examples of University Departments currently offering schemes of study in this area are presented which represent three alternative levels of commitment to education in this subject area. At MIT the Department of Chemical Engineering has traditionally maintained a strong graduate program in Fuel Engineering which represents only one specialist subject area in a comprehensive Chemical Engineering curriculum. The Department of Chemical Engineering and Fuel Technology at the University of Sheffield has maintained a very strong commitment to both

subjects at graduate and undergraduate levels. The Department of Fuel and Combustion Science at the University of Leeds offers both graduate and undergraduate degree schemes devoted exclusively to the subject of Fuels.

Fuel Engineering Courses at MIT

In common with many Engineering Schools in Departments of Mechanical and Nuclear Engineering at MIT offer specialized graduate courses which are related to certain areas of Fuel Engineering. Courses in Combustion, Thermal Power System, Energy Conversion and Nuclear Fuels fall into this category. The Department of Chemical Engineering is one of the few departments in the country to offer a coordinated scheme of study at the graduate level in Fuel Engineering. This scheme of study is completely optional and represents only one possible area of graduate specialization amongst a total of twelve Chemical Engineering topics. An integrated program in this area, leading to an M.Sc, requires a total of 66 credit hours at least 42 of which must normally be obtained from the following list of courses subjects:

Subject	Credit hours
Energy Technology	9
Chemical Engineering Thermodynamics	12
Mechanics of Fluids	9
Catalysis and Catalytic Processes	9
Absorption and Catalysis	9
Chemical Reaction Engineering	9
Principles of Combustion	9
Seminar in Air Pollution Control	9
Seminar in Fuel Conversion and Utilization	9
Radiative Transfer	9
Nuclear Chemical Engineering	12

In addition, a research thesis is required and the Department Fuels Research Laboratory together with the MIT Energy Laboratory provide excellent facilities for research on a wide range of fuel processing and combustion topics. Normally the general requirements for an M.Sc. degree can be met within one academic year.

The general philosophy in respect to education in Fuel Engineering is to treat the subject as a specialized area of Chemical Engineering. Courses are presented only at graduate level and require a firm background in the general principles of Chemical Engineering. However, the courses are available to undergraduate students in their senior year as restricted electives. This approach to graduate education in Fuel Engineering inevitably leads to a considerable degree of specialization. The very nature of graduate-course work usually precludes much of the less intellectually demanding qualitative material associated with some of the more pragmatic aspects of Fuel Engineering . At MIT the areas of specialization reflect the department's strong interest in Chemical Engineering aspects of Fuel Processing. Combustion and Air Pollution. Several other engineering schools offer graduate courses which cover other important aspects of Fuel Engineering such as Resource Recovery, Thermal Power Engineering and Energy Management. In general, it is felt that even though very few graduates obtain degrees specifically in Fuel Science and Engineering, there is a sufficient pool of specialist graduates to meet the demands of the upper level managerial, research and development areas of the fuel and energy sector.

The Department of Chemical Engineering and Fuel Technology, University of Sheffield, England.

Before discussing the structure of the graduate and undergraduate courses offered by the Department of Chemical Engineering and Fuel Technology at the University of Sheffield, it is worthwhile to point out the general differences, particularly in respect of entrance requirements, between U.K. and American Universities. In general U.K. students are a year older than their American counterparts on entering a university. They will have spent two years studying three or four subjects appropriate to the area of university study they wish to pursue. For instance, most students wishing to enter Chemical Engineering Schools will have studied Maths, Physics and Chemistry. Each university and university department is then free to set whatever entrance requirements it feels necessary for specific degree courses. Eligibility for entrance is then judged on the basis of individual students performance in national examinations conducted by independent examining bodies. Entrance requirements are consequently somewhat more stringent in the U.K., and the students are equipped to commence their undergraduate degree courses at a higher academic level than freshmen in American Universities. As a result most undergraduate courses are only three years in duration, leading to the Bachelors degree. By the time of entrance, students have already chosen their subject areas, and specialists courses in the appropriate subjects are given during the first year.

The scheme of study at undergraduate level, offered by the Department of Chemical Engineering and Fuel Technology at the University of Sheffield, consists of courses during the first two years with optional subjects in the final undergraduate year. Students are required to obtain satisfactory results in all prescribed subjects at the end of the second year before being allowed to proceed to the final year. Progress is monitored essentially by formal written examination at the end of each year. The results of these examinations determine whether or not the student is considered for an Ordinary or Honours degree.

First year subjects are mostly extension of Maths, Physics and Chemistry, general engineering courses and introductory courses to Fuel Technology and Chemical Engineering which represent about 20% of the total course load. These courses are designed to equip the student for the more advanced courses in the second and final year's scheme of study. Laboratory classes in the first year introduce students to many of the practical aspects of Fuel Technology including properties and testing of solid, liquid and gaseous fuels. During the second year the prescribed scheme of study consists of courses in,

Fuel Technology	Mechanical Engineering	Maths
Chemical Engineering	Elector-Technology	Chemistry

The Fuel Technology and Chemical Engineering courses occupy approximately 50% of the course work. At this stage, Chemical Engineering courses deal essentially with the fundamentals of Heat, Mass and Momentum Transfer at quite an advanced level. The Fuel Technology courses deal with some of the general aspects of Fuels including handling and processing, and introduction to some of the more practical problems associated with the combustion of different types of fuels. After successfully completing the first two years of prescribed undergraduate courses, students then have the option of choosing between final year schemes of study in either Chemical Engineering and Fuel Technology or Environmental Chemical Engineering. The prescribed courses of study for these two options are given below;

Either (i) Chemical Engineering and Fuel Technology

Chemical Engineering Operations	Fuel Processing
Control and Instrumentation	Direct Electricity Generation
Nuclear Reactor Engineering	Combustion Theory
Business Economics	Refractions Technology

or (ii) Environmental Chemical Engineering

Chemical Engineering Operations	Project Evaluation with respect to Pollution Control
Control and Instrumentation	Medical and Legal aspects of Pollution
Environmental Chemical Engineering	

together with any three of the following advanced topics:

Fluid Dynamics
Advanced Combustion Theory with Gas Dynamics
Heat Exchanges
High Temperature Chemical Engineering
Process and Project Engineering
Advanced Topics

In addition during the final year students are required to undertake either an experimental investigation or a design study of some problem of Chemical Engineering or Fuel Technology.

These course details clearly show that the subject of Fuel Technology can be included as a major element in a Chemical Engineering curriculum at undergraduate level. However, it should be realized that much of the course material on fuels is contained in the final year of study, and as such, the overall effect is to provide basic core of Chemical Engineering courses around which the subjects of Fuel Technology, and in particular, Combustion are handled primarily from a Chemical Engineering and Processing point of view.

In common with most other U.K. University Departments, the Department of Chemical Engineering and Fuel Technology offers both Master's and Doctorate research programs requiring no formal course work. However an advanced course on Combustion Science and Pollution Control is also offered, which leads to the award of a Diploma or Master's Degree by examination. The course consists of two full terms of lectures, seminars and experimental work on topics which include:

Physical Chemistry of Combustion
Connective Heat Transfer
Radiative Heat Transfer
Theory and Technology of Combustion Process
Minor Constituents of Flames and Combustion Gases
Combustion Noise and Oscillations
Flame and Plasma Reactors
Open Flames, Flares and Incinerators, Plume Dispersion
Furnace Refractories
Measurement and Control in Flames (Experimental Techniques)
Mathematical Models of Combustion Systems.

In addition, students prepare a dissertation in either a design study or a research project, which is completed after the course work and can serve as an introduction to a Ph.D. course.

This Master's course is open to graduates in engineering, physics, chemistry and mathematics.

The Department of Fuel and Combustion Science at the University of Leeds.

Instruction and research in fuel science have been provided by the University of Leeds since 1906, and courses are currently offered at the undergraduate level in Fuel and Energy Engineering and in Fuel and Combustion Science. The courses are offered by the Department of Fuel and Combustion Science which is the only University Department in the U.K. to offer undergraduate schemes of study devoted exclusively to the subject of fuels. The department providing these schemes of study is the founding member of the Houldsworth School of Applied Science. The school itself consists of five departments which, although independent in themselves, have so much in common that they have elected to work together as a group. These departments are Fuel and Combustion Science, Chemical Engineering, Metallurgy, Ceramics and Mining and Mineral Sciences. The school organization allows the various departments to share lecture rooms, the library, common rooms, workshops and many items of costly equipment which could not easily be provided separately. In addition, the departments provide carefully tailored service courses in specific subject areas for students from other departments within the school.

The Department currently offers four undergraduate degree programs,

- B. Sc. Fuel and Combustion Science
- B. Sc. Fuel and Energy Engineering
- B. Sc. Chemistry/Fuel and Combustion Science
- B. Sc. Fuel and Energy/Management Studies

The first two of these schemes involve only the Fuel and Combustion Science Department. Both are essentially three year courses and have a basic theme in common but are varied to cater to the individual ability and intentions of the student. The Fuel and Combustion Science course contains rather more basic science than the Fuel and Energy Engineering course, which as its name implies, is biased more towards engineering and technological aspects. Broadly, but not exclusively, the former is intended to equip graduates for entry into the research and development sectors of the industries supplying and using fuels and the latter is intended for future designers and builders of plant and equipment for the large-scale processing or use of fuels.

The last two undergraduate degree schemes are combined courses offered jointly with the Departments of Chemistry and Management Studies. The Chemistry/Fuel and Combustion Science scheme of study allows the chemistry-minded student to carry this subject further while at the same time receiving sound training in the science of fuel and combustion. The combined course in Fuel and Energy/Management studies is aimed at providing both a firm technological and engineering appreciation of fuels and energy for students wishing to follow conventional courses in Management Studies. This combination of courses is hoped to provide the correct blend of technological and managerial knowledge required for the new generation of fuel and energy managers.

The Honour's degree schemes of study for both Fuel and Combustion Science and Fuel and Energy Engineering are given below.

First Year- courses are essentially common for both degree schemes.

Fuel and Energy Sources	Maths
Fuel and Energy Utilization	Physics
Materials Science	Physical Chemistry
Computational Techniques	

Second Year- again the majority of fuel courses are common, the only differences being in the subsidiary subjects.

Fuel and Combustion Science		Fuel and Energy Engineering
	Combustion Technology *	
	Fuel Processing and Flow of Materials *	
	Power Generation I *	
	Instrumentation and Control *	
	Fuel and Energy Economics *	
	Applied Physical Chemistry *	
	Heat Transfer I *	
	Chemical Engineering (Unit Operations) *	
Physics		Mathematics
Chemistry (Organic)		Engineering (Mechanical and Electrical).

(* Common Courses)

Third Year- all courses are given by the Department.

Fuel and Combustion Science		Fuel and Energy Engineering
	Combustion Aerodynamics and Heat Transfer *	
	The Efficient Use of Energy *	
	Management and Organization of the Energy Industries *	
Combustion and Explosion		Petroleum and National Gas Engineering
Petroleum and National Gas Science		Fuel and Combustion Plant Design
Coal and Carbon Science		Power Generation II

(* Common Courses) In addition to the above courses, students are required to conduct an experimental research project on some aspect of fuel and combustion science or energy engineering.

Courses for the combined degree schemes in Chemistry/Fuel and Combustion Science and Fuel and Energy/Management Studies consist of combinations of some of the above courses with selections of standard courses in the Departments of Chemistry and Management Studies, respectively.

Schemes of study are also offered at graduate level leading to

- M. Sc. Combustion and Energy
- M. Sc. Environmental Pollution Control.

The latter course is run in conjunction with several other university departments, though combustion and fuels-related pollution aspects are covered by the department. The former course is offered by the Center for Combustion and Energy Studies which draws upon the expertise of the Departments of Fuel and Combustion Science, Mechanical Engineering and Physical Chemistry. Both of these graduate programs take one complete academic year and include both course work and a research exercise.

Discussion

The major differences in approach to education in Fuel Science and Engineering in the three Departments discussed here are ones of scope and breadth of coverage. Treatment at graduate level without any prior introduction to the subject of Fuels leads inevitably to a considerable degree of specialization, usually in some area amenable to a qualitative and analytical approach, such as combustion. The inclusion of Fuel Science and Engineering courses at undergraduate level can readily be integrated into 9 Chemical Engineering curriculum without seriously affecting the basic elements essential for education in Chemical Engineering. This approach can eliminate the need for specialization in one particular area and can lead to a well-rounded appreciation of the engineering significance of fuels. Undergraduate schemes of study devoted exclusively to the study of fuels provide an extremely broad training in all aspects of Fuel Science and Engineering. The major advantage of this approach is that it provides sufficient coverage of many important qualitative, practical and technological aspects in all areas

of Fuel Science and Engineering. Hence not only are the more academically inclined students able to pursue careers in research and development, but the more practically-minded students are well prepared to enter the operational side of many industries making or using fuels. It is often at this level where many important decisions affecting fuel and energy usage are made particularly in the small to medium size industries.

It is always easier and usually safer to alter the superstructure rather than the foundation of any particular institution. Consequently it is felt that any charges deemed necessary in the education of Fuel Science and Engineering in the U.S.A. will take place predominately in graduate schools by alteration of existing courses or implementation of new courses. However, it is felt that many of the important subjects, particularly fuel and energy utilization, can best be included at undergraduate level.

Fuel Science and Engineering courses can easily be integrated into a Chemical Engineering curriculum and the provision of such courses could certainly help to provide the technological background so often missing in graduate level courses.