COURSES IN FLUID MECHANICS AND CHEMICAL REACTION ENGINEERING IN EUROPE

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Professor H.E. Armstrong taught the first chemical engineering course in the world in 1885 at the Imperial College of London, and in 1888, Professor George E. Davis, Manchester University, published *Chemical Engineering*, describing a course divided into twelve lessons. At the same time, Professor L. Mills Norton established the first degree in chemical engineering at the Massachusetts Institute of Technology, where the first ChE department was founded in 1888. In Europe, Germany was the first country with ChE departments (1970) at the universities of Erlangen, Karlsruhe, and Dortmund.

In the first half of the 20th century, the ChE curriculum was focused on physical operations and industrial chemistry courses, but during the decade of 1955 to 1965, there were decisive changes; courses concerning transport phenomena appeared and were useful for unifying the physical bases of unit operations, followed by courses concerning fluid mechanics (FM) and chemical reaction engineering (CRE).

Understanding the phenomena and the principles that govern reactor behavior (*i.e.,* the study of CRE) is one aspect that currently distinguishes a ChE graduate from a physical or mechanical engineer. CRE is a general methodology for approaching any system where reactor engineering is required. The discipline uses different tools (mathematics, physics, etc.) to develop knowledge of the systems, especially the fluid behavior in the reactors. Consequently, CRE and FM are two disciplines very important to the ChE curriculum.

Books on these two disciplines are numerous. We would like to highlight some of them. As regards FM, a book by Cheremisoff[1] treats different aspects as the simple fluid flow, flow measurement, mixed-flow equipment, gas-liquid fluid flow, solid/gas, and solids. A book by Holland and Bragg[2] treats fluid behavior in a simple way, with some interesting examples. Books by Astarita[3] and Harris,[4] and in a singular way a book by Bird, *et al.,*[5] treat rheology and non-Newtonian fluid flow. Another book in this field is one by Coulson and Richardson[6] on fluid mechanics; this is one of the most-used texts in Europe.

With respect to CRE, the first major book appeared in the late 1940s as Volume 3 of the now-classical *Chemical Process Principles,* by Hougen and Watson.[7] This was followed by several books in the 1950s and 1960s, such as Smith's *Chemical Engineering Kinetics,*[8] Levenspiel's *Chemical Reaction Engineering,*[9] Astarita's *Mass Transfer with Chemical Reaction,*[10] and Danckwert's *Gas-Liquid Reaction.*[11] In the 1970s, a new series of books appeared with more emphasis on the analysis and mathematical modeling.[12-16] Out of all the CRE books, we want to highlight two by Levenspiel: *Chemical Reaction Engineering*[9] and *The Chemical Reactor Omnibook.*[17] The former presented the organization and systematization of CRE knowledge, and the recently published third edition[18] is an enrich-

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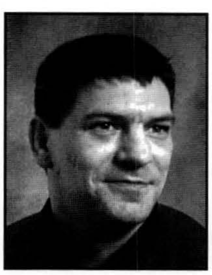

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The objective of this paper is to analyze the teaching of FM and CRE around Europe through a survey sent to over 100 European chemical engineering departments. The survey asked about time allocated to classes, books and tools used, and the number of students per class, among other things.

ment of the other editions with a structure similar to that of the *Omnibook*.

The objective of this paper is to analyze the teaching of FM and CRE around Europe through a survey sent to over 100 European chemical engineering departments. The survey asked about time allocated to classes, books and tools used, and the number of students per class, among other things. The results of this study will then be compared with the work reported by Dudukovic,[16] which analyzed CRE courses in U.S. and Canadian universities in 1982.

OBJECTIVES OF THE SURVEY

The European continent is changing rapidly. Nowadays, fifteen countries from the European Union (EU), together with Switzerland and Norway, form the European Economic Space, enabling citizens from each country to move freely between countries and to work in the other countries of the Space. Furthermore, since the fall of the Berlin wall in 1989, contact with the eastern block countries has increased to the point that Poland, Hungary, and the Czech Republic will most likely join the EU soon. This situation demands that European universities must now offer students a valid graduate degree that will be recognized in all the countries. As a consequence, university studies have undergone many changes. Chemical engineering studies are greatly affected by all these changes, and it has become necessary to determine what aspects neighboring countries consider most important in each of the ChE topics.

This paper will analyze how fluid mechanics and chemical engineering reaction topics are taught in the ChE undergraduate courses. Two surveys (one for FM and the other for CRE) were sent to a total of 107 universities throughout Europe (91 in the European Economic Space and 14 in the former eastern block). Responses were obtained from 68 and 70 ChE departments for the FM and CRE surveys, respectively, representing 63% and 65% of the departments con-

TABLE 1
Courses and Time Allocated to FM and CRE

	FM	CRE	CRE North America
1. *FM/CRE Courses Available for Undergraduates*			
One	31	22	69
Two	22	38	25
Three	33	21	5
Four	8	19	1
Five	6	0	0
2. *FM/CRE Courses Required for Undergraduates*			
One	49	48	91
Two	33	43	9
Three and more	18	9	0
Graduates			
None	52	57	27
One	41	31	58
Two and more	7	12	6
3. *Hours Allocated to FM/CRE Courses*			
a) Lectures/course			
Less than 20	12	11	-
21 to 40	47	40	-
41 to 60	26	40	-
61 to 80	12	3	-
Over 80	3	6	-
b) Problem solving/course			
Less than 10	15	17	-
11 to 20	41	33	-
21 to 40	38	33	-
41 to 50	3	11	-
Over 51	3	6	-
c) Laboratory/course			
Less than 10	36	46	-
11 to 20	36	14	-
21 to 40	25	20	-
41 to 50	3	6	-
Over 51	0	14	-
4. *Estimated Average Class Size*			
Basic FM/CRE	60	56	
Other FM/CRE	29	29	
5. *Experiments Available in Laboratory of FM/CRE*			
None	19	14	54
1 to 3	51	50	41
4 to 6	12	22	4
Over 6	18	14	1
6. *Industrial Input in FM/CRE Course*			
None	24	27	62
Some	67	70	34
A lot	9	3	4
7. *Describe the Industrial Input*			
Instructor had industrial experience	64	42	35
Case studies are treated	52	58	26
Instructor is from industry	6	6	9
Seminars by industry personnel	9	25	9
Field trips	30	22	7
Other	12	14	14

tacted. The responses were from the United Kingdom (29%), Spain (20%), Germany and Poland (9% each), France and Italy (6% each), and smaller numbers from the Czech Republic, Hungary, Ireland, Portugal, Romania, Slovenia, and Switzerland. The structure of the survey was similar to the one presented by Dudukovic for U.S. and Canadian universities in the early 1980s. Additionally, the results of the survey will be compared with the Dudukovic's results in the CRE field in order to point out the differences we observed between Europe and North America.

FM AND CRE COURSES: DEDICATED TIME AND ORGANIZATION

Table 1 shows the first seven questions of both surveys (FM and CRE), the corresponding results, and Dudukovic's data for North America. European universities offer an average of two courses of both FM and CRE. The number of universities offering one, two, or three courses is almost the same, whereas very few universities have additional courses for chemical engineering students. Contrarily, only 31% of the North American universities offer more than one course for CRE. Another important point is that almost 50% of the European universities require one course per topic for the undergraduate students, whereas the other 50% need at least one more; meanwhile, in North America there is a solid agreement (91%) for requiring only one course in the undergraduate program. As a consequence, it can be said that European universities offer one course more than required in the undergraduate studies program.

Question 4 asks about the average number of students per class. There is a homogeneous answer of 60 for the main course and 30 in other courses, which indicates good teaching quality.

The length of the different courses was analyzed by asking about the time allocated for regular-theoretical lectures, problem-solving seminars, and laboratory. Half (47%) of European FM courses require 20-40 hours, followed by 26.5% that require 41-60 hours. Problem-solving seminars are mainly grouped around 11-40 hours for both FM and CRE, whereas the time allocated to laboratory sessions shows wide disparity. For example, for CRE courses, 45% of the universities give more than 51 hours/course. The laboratory classes are directly related to Question 5, where the number of experiments available in laboratory classes is asked. Half of the European universities present 1 to 3 laboratory experiments per course, while fewer than 20% do not offer any. The North American survey showed that 54% of the universities did not give laboratory exercises, but obviously that situation cannot be extrapolated to the present time. The conclusion that can be drawn is that the number of universities that do not impart laboratory experiments has decreased to only 20%. On the other hand, nearly 20% of the universities currently offer more than 6 experiments, where only 1% offered such a number in the 1980s.

Another important aspect in the teaching of chemical engineering is the amount of industrial input in the classes. In North America in the 1980s, about 40% of the universities declared that they incorporated industrial input into the teaching, while in Europe today, over 70% of the universities indicate that they introduce industrial elements into the curriculum. It is important to point out, however, that in the North American survey only one answer per question was permitted, while in the European survey the universities were able to select multiple options; consequently, the comparison can only be done from a qualitative point of view.

For CRE instruction in North America, industrial input consisted of the professor's own industrial experience (35%) and the use of case studies (26%). A similar result was

TABLE 2
FM Topics, Objectives and Textbooks

1. Objectives of basic FM course as perceived by lecturers
(1=most important, 2= second most important, etc.)

Potential and internal flow	1.7
Biphasic gas-liquid flow	3.9
Piping, accessories, and pumps	1.8
Flow measurement	2.3
Filtration and sedimentation	3.4
Fixed and fluidized beds	3.9
Mixers, stirrers	4.1

2. Course dedicated to various key concepts

	Main	Other
Fluid systems	75	61
Solid fluid systems	25	39
TOTAL	100%	100%
Theoretical background	64	70
Descriptive background	36	30
TOTAL	100%	100%

3. Most frequently used textbooks for FM (multiple choice allowed)

Astarita, G[3]	9
Cheremisoff[1]	12
Coulson and Richardson (Fluid Mechanics)[6]	73
Davidson, et al.[20]	15
Holland and Bragg[2]	30
Kunii and Levenspiel[21]	21
Massey[22]	9
Darby[23]	9
White[24]	6
Levenspiel (Fluid Mechanics)	6

4. Did you replace the text in the last five years?

No	55
Only temporarily	16
Yes	29

5. Are current books satisfactory:

No	3
Somewhat	30
Yes	67

obtained in Europe. It is only remarkable that in Europe, 25% of the institutions reported that special seminars managed by industrial representatives were given. FM courses show different results; over 60% of the professors had previously worked in industry. Additionally, field trips to visit factories are also numerous (30%); it is possible that this percentage is bigger in Europe than in North America due to the fact that Europe is much smaller and distances are not a problem in planning visits.

TABLE 3
CRE Topics, Objectives and Textbooks
(previous data for North America included)

1. Objectives of basic CRE course as perceived by lecturers *(1=most important, 2= second most important, etc.)*

	Europe	North America
Ideal reactors concept	1.7	1.6
Interpretation of kinetic data	3.2	2.4
Design of actual reactors	2.6	2.9
Reactor modeling and analysis	2.6	3.0
Kinetics and mechanisms	3.7	3.1
Transport kinetic interactions in heterogeneous systems	3.1	3.3

2. Course dedicated to various key concepts

	Europe Main	Europe Other	North America Main	North America Other
Homogeneous systems	63	28	77	35
Heterogeneous systems	37	72	23	65
TOTAL	100%		100%	
Ideal reactors	65	45	82	53
Non-ideal reactors	35	55	18	47
TOTAL	100%		100%	
Stirred pots	45	38	49	34
Tubular and packed bed reactors	47	44	33	48
Fluidized beds	8	18	18	18
TOTAL	100%		100%	

3. Most frequently used textbooks for CRE (multiple choice allowed)

	Europe	North America
Levenspiel[9]	75	58
Hill[26]	8	25
Smith[8]	30	14
Froment and Bischoff[14]	41	7
Fogler[15]	56	6
Carberry[12]	8	4
Levenspiel (Omnibook)[16]	39	-
Coulson and Richardson (Vol. 3)[28]	28	-
Westerterp, et al.[19]	22	-

4. Did you replace the text in the last five years?

	Europe	North America
No	56	44
Only temporarily	18	18
Yes	26	38

5. Are current books satisfactory:

	Europe	North America
No	6	6
Somewhat	30	37
Yes	64	57

TOPICS, OBJECTIVES, AND TEXTBOOKS FOR FM COURSES

In this section the results shown in Table 2 are analyzed. (In this case, no comparison with previous surveys or programs can be given.) Basically, there are two main groups in fluid mechanics: 1) the fluid dynamics, flow, and equipment (fluid systems), and 2) fluid dynamics when the fluid is in contact with solid particles (fluid-particle systems). The first question in Table 2 asks professors to rank seven parts of a fluid mechanics course in order of importance. The results show that "Potential and Internal Flow" and "Piping, Accessories, and Pumps" are the most important parts of the FM course, followed by "Flow Measurement." These three parts belong to the fluid-systems group and are considered by the instructors to be much more important than the fluid-particle system topics. Much lower in importance was the "Biphasic Gas Liquid Flow" and the areas belonging to fluid-particle systems.

These results are consistent with the answers obtained to the second question: 75% of course time is dedicated to fluid systems. For other more advanced courses in FM, fluid systems are still dominant, but at a lower level (61%). It is important to point out that in the survey some universities responded to both the main and the other courses, whereas some only responded to the main course, possibly due to the fact that they only require one course in the curricula. The analyzed results considered all the universities. Surprisingly, no differences were found and there is clear agreement that in the FM main course, fluid systems are considered more important and take more time than fluid-particle systems. It is also important to point out that for a main or other FM course, about 70% of the time is dedicated to theoretical aspects and 30% to a description of equipment and situations.

The textbooks favored by the instructors are analyzed in the third question. It is important to remark that the situation in Europe is very different from that in North America. The U.S.A. and Canada are English-speaking countries, while in Europe a huge number of languages live together in a much smaller land. Only books with at least an English edition were considered in this study since English is accepted as a second language in most European universities, although there is a clear tendency in Germany to use books of German authors written in German.

Most departments (73%) follow Coulson and Richardson's Chemical Engineering collection, which indicates a high level of agreement in teaching FM throughout Europe. Other general textbooks used are Holland and Bragg's *Fluid Flow for Chemical Engineers* (30%) and Cheremisoff's *Encyclopedia of Fluid Mechanics* (12%). Some other general textbooks are consulted by less than 10% of the departments, including those by Massey, Darby, White, and Levenspiel. It is noteworthy that several universities use the recently published (1996) Darby book. Also, some books on specific topics are highly consulted, such as the books of Kunii and Levenspiel (22%), and Davidson, et al. (15%).

The answers to questions 4 and 5 in Table 2 reveal that a majority of instructors (95%) are satisfied, or at least somewhat satisfied, with the textbook used, and that 70% of them have not replaced the book in the last five years.

TOPICS, OBJECTIVES, AND TEXTBOOKS FOR CRE COURSES

In this section, the results for specific teaching objectives of CRE are presented, analyzed, and compared with the results of Dudukovic's survey of Canadian and U.S. Universities (see Table 3).

The first question asks the departments to rank the CRE courses as to their importance. The same topics were used as in the Dudukovic survey in order to make a direct comparison with the 1980s. In North America, the most important topic was the ideal reactors, followed by the interpretation of kinetic data and the design/modeling of reactors; reaction mechanism and transport kinetics had similar importance.

The present survey reveals that in Europe the ideal reactor concept is also the most important (1.8), followed now by the design, modeling, and analysis of actual reactors (2.6). Contrarily, all the aspects related to kinetics are secondary. In summary, the only difference from Dudukovic's results is that now the interpretation of kinetic data has a lower importance with respect to the design and modeling of reactors—perhaps due to the fact that some of these topics are covered in other courses.

The question concerning time allocated to different concepts shows that the principal CRE course is dedicated to homogeneous systems, while other courses are more specific for heterogeneous systems—very similar to the North American survey results. There is also agreement with the Dudukovic survey as concerns ideal/non-ideal reactors, *i.e.,* the basic course is dedicated to ideal aspects, and non-ideal concepts are dealt with in other courses.

For textbook analysis, the same criteria used in the FM section were used. In the 1980s, North American professors preferred Levenspiel (58%), Hill (25%), and Smith (14%), and the present survey showed that European professors also prefer the Levenspiel textbooks (*Chemical Reaction Engineering* with 75% and *Omnibook* with 40%). Other books that ranked poorly in 1980, however, are widely consulted in Europe today: Fogler (56%), Froment and Bischoff (42%), and Coulson and Richardson (29%). Again, it is important to note that over 95% of the professors are satisfied or somewhat satisfied with the textbook they are using.

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