Trends in Chemical Engineering

By N. Ibl *

Technisch-Chemisches Laboratorium der Eidgenössischen Technischen Hochschule, Zürich

Public lecture delivered at the University of Newcastle on March 14, 1968

1. The Problem of Industrial Chemistry

Mass consumption of goods of all sorts is a characteristic feature of our civilization, which distinguishes if from all other civilizations our earth has known before us. But mass consumption is possible only with mass production. Indeed our industry is turning out goods at an ever increasing rate. The expansion of the chemical industry is particularly remarkable. This is illustrated by Fig. 1 which shows the evolution of the production of a number of key chemicals during the last fifty years. During that period the yearly rate of increase has kept growing, i. e. the curves have an outspoken exponential character, and the end of the trend is not in sight. The curves of Fig. 1 seem to contradict the old saying that trees do not grow into the sky. At present, the world production of ammonia and its derivatives reaches 24 million tons per year. It is remarkable that such an aggressive and

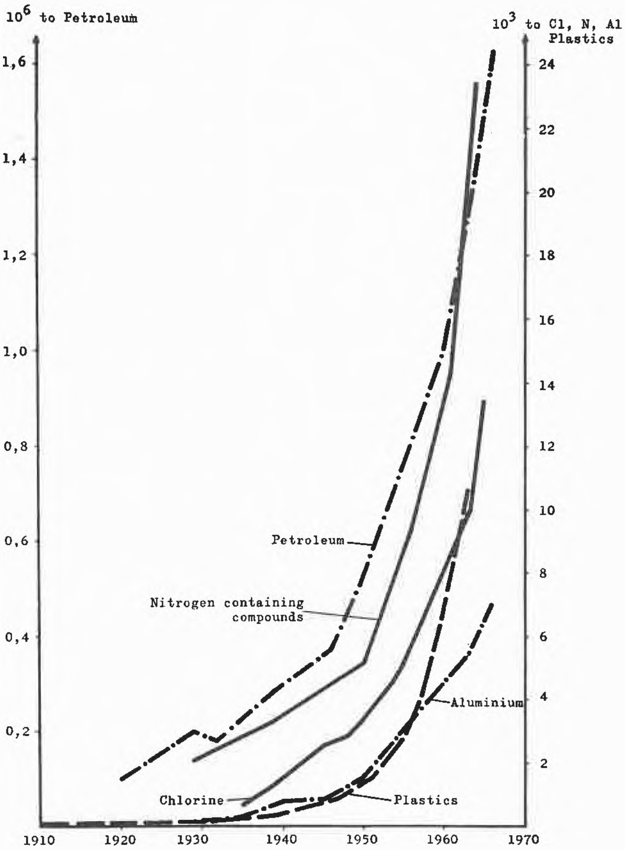


Fig. 1. World Production of Key Chemicals (per year)

* "Marchon Lecturer" at the Department of Chemical Engineering of the University of Newcastle (England), March 1968.

toxic chemical as chlorine is turned out at the rate of 15 million tons a year, enough to cover a city of the size of Zurich or Newcastle with an atmosphere of pure chlorine to over a height of 300 feet. Owing to this explosion of production, chemistry is facing with increasing intensity a problem raised by its own success or more exactly by the success of its applications. It is the manufacturing at low cost of the chemicals which the contemporary way of life requires in such huge quantities. Traditionally, chemistry is an experimental science, whose home is the laboratory. Chemistry was borne in the retort and the experiment in the laboratory has remained the backbone of the chemist's activity ever since. The theoretical foundations of chemistry have made immense progress and the experimental techniques of the chemist may have become very sophisticated, but his approach to theoretical and experimental problems is not that of an engineer. The primary concern of the chemist is the synthesis of new compounds, the elucidation of the molecular structure of chemical substances and the study of their chemical and physical properties. The chemistry curriculum of the universities is chiefly designed to train him for this type of activity. The question thus arises who is the professional man who is going to develop a commercial process from a synthesis made in the laboratory, who should be entrusted with the design and the operation of a chemical plant. Depending on the times and on the country the answer has been a different one.

Already in the early stages of chemistry, before the beginning of this century, a number of products were manufactured industrially by chemical or electrochemical processes. However, until the first world war, the quantities involved were in general small and the techniques used were very similar to those of the laboratory. In the case of the few products which were manufactured on a somewhat larger scale the necessary equipment was designed either by chemists who had developed some engineering skill, or by mechanical engineers. Somewhat later, in the larger plants, teams of chemists and mechanical engineers were formed, the former providing the chemical know-how, the latter ones designing the apparatus.

With the growth of the chemical industry this scheme became less and less adequate. The educational backgrounds of the chemist and of the mechanical engineer were too different, they didn't speak the same language and a gap of understanding developed between them, when the problems to be solved became more complicated.

2. The Pecularities of Large Scale Chemistry

Indeed, the industrial application of chemistry involves problems of its own, which are extraneous to both chemistry and mechanical engineering. I shall try to illustrate this by a few simple examples. If we carry out in the laboratory a chemical reaction which requires heating we may do it by placing a Bunsen burner under the flask or vessel in which the reaction takes place. If we use 10 times as much heat as the reaction really needs, we don't care. But if we are producing a cheap compound by the thousands of tons, it is most important that the heat losses be minimized and the energy consumption be as small as possible. Problems of heat balance and heat transfer are therefore of great importance in industrial practice whereas they are of little interest to the chemist in the laboratory. As a second example let us consider two vessels of different size in which the same exothermic reaction takes place (Fig. 2).

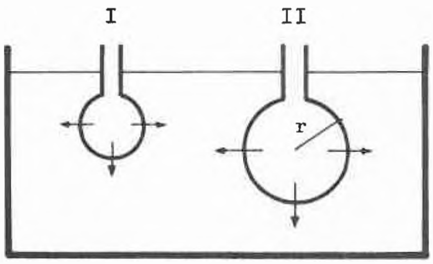


Fig. 2. Same Exothermic (Heat Evolving) Reaction in I and II

Quantity of substance reacting per unit time $\sim r^3$
Quantity of heat generated per unit time $\sim r^3$
Quantity of heat transferred per unit time $\sim r^2$

Consequence: Temperature in II higher than in I
Reaction in II faster than in I

This heat is transferred to the water of a container in which the vessels are dipping. The amount of substance reacting per unit time in each vessel is proportional to its volume and therefore to the cube of the radius of the spherical vessel. The quantitiy of heat which is produced in the reaction, is in its turn proportional to the quantity of substance which reacts, and therefore also proportional to the cube of the radius. On the other hand, the quantity of heat transferred per unit time from each of the vessels to the surroundings is proportional to the area of the wall of the vessel, and therefore proportional to the square of the radius. The result is that, relatively to the quantity of substance which reacts, less heat is carried away from the large than from the small vessel. Therefore, owing to the exothermic reaction, the temperature in the large vessel will increase more than in the small one. Now, the rate of a chemical reaction much depends on temperature. Unless we take appropriate measures the reaction in the large vessel will therefore proceed faster than in the small one and may even lead to an explosion. Therefore, the development of a synthesis from the laboratory stage into a large scale industrial operation does not only require the design of much larger and more sturdy equipment, it also involves that the process itself can be seriously altered by the change in size and that this effect must be properly taken care of. The scaling up of a chemical process is a typical industrial problem which neither the chemist nor the mechanical engineer has been trained to handle.

I shall now give a third example of a characteristic difference between chemistry in the laboratory and in a large scale manufacturing process. When the chemist makes a synthesis, he fills a vessel with the reacting substance, waits until the reaction is completed, removes the mixture from the vessel and carries out any further processing, such as distillation or filtration, which may be necessary. He works batchwise. In a large plant this procedure is not popular because it is usually uneconomic. Here, whenever possible, the reacting substances are continuously fed into a reactor and the products continuously removed from it. The preliminary and subsequent processing which is usually associated with the chemical reaction proper, is also preferably carried out continuously. Continuous flows of gases, liquids and solids go through the plant and interact in a complicated manner. Problems of fluid flow, of mass transfer and of mass balances, the optimization of the pipe network etc. are thus important, whereas the knowledge of such subjects is of relatively little interest to the chemist. In contrast to the situation encountered in the laboratory, the plant represents a complicated system which is often extensively automatically controlled, and must be operated in such a manner that the overall cost is a minimum. Economic considerations are always of primary concern in industry, whereas for instance if we establish the constitution or the properties of a compound, it plays in principle no role whether we achieve this by the cheapest possible method or not. We should use the most powerful technique, not necessarily the cheapest one, and hope that someone provides the grant.

I have mentioned so far some typical examples of the differences between chemistry in the laboratory and in its industrial applications. But a similar gap exists between the activities of a mechanical engineer in a chemical plant and in a factory with normal mechanical engineering problems. To mention only one aspect for the sake of illustration, the mechanical engineer is afraid of the often highly corrosive, not seldom toxic or even explosive substances which the chemist presents to him. He has no feeling for handling them and is not at home in chemistry. The problem of the choice of the construction materials, especially of their corrosion resistance, is much more complex and widespread than in classical mechanical engineering. In general, the interaction between chemistry and plant design is a characteristic feature of chemical engineering which distinguishes this discipline from both chemistry and classical engineering.

3. The Chemical Engineer

As I mentioned at the beginning, in the early days of the chemical industry the plants were designed and operated by teams of chemists and mechanical engineers. But owing to the situation which I have just sketched, this scheme became less and less satisfactory as the chemical industry became bigger and its techniques more sophisticated. In the USA, and also in England, the conclusion was made that the challenge of the rapidly growing chemical industry of the twenties and the thirties could be met only be creating a new profession, that of the chemical engineer. Soon after world war I, chemical engineering was established in the USA as a separate branch of engineering, a discipline of its own beside the traditional engineering branches: civil, mechanical and electrical engineering. At present, in the US, 2700* bachelor's degrees in chemical engineering are granted per year. This represents 9% of the total number of engineering degrees of the same level. The corresponding figure for the doctor's degree is 20%.

In the beginning, which can be traced back in America to the period immediately preceding world war I, chemical engineering was, however, hardly more than chemical technology. The chemical engineering student received a training both in chemistry and mechanical engineering, and acquired additional knowledge, mainly of a descriptive nature, of the principal industrial chemical processes in operation at that time. The first major step toward generalization and abstraction was made in the twenties when the concept of unit operations was developed. The basic idea is that the whole process is decomposed into elements which remain essentially the same independently of the process. Typical examples are distillation and filtration which will be carried out much in the same way irrespectively of the chemical which is being produced. The whole plant is then built up and "synthetized" from the elements. The principle is similar to that of the engine elements into which the mechanical engineer decomposes its devices and which remain essentially the same from one engine to the other. The principle of the unit operation has been very successfully applied to separation techniques of a mainly physical nature, such as distillation, crystallization, dissolution or filtration. It was attempted to extend this method to the chemical reactions and to regard certain types of reactions (for instance hydration, alkylation or chlorination) and the corresponding reactors as a unit process, but this was never really successful. Nevertheless, the unit operations approach brought order into the great variety of the chemical manufacturing processes which was already increasing fast during the period between the two world wars. Presently about 300 inorganic substances and some 20000 organic compounds are manufactured on an industrial scale.[1] If a substantial number of the corresponding processes was to be covered in a curriculum of chemical engineering only an enumeration, a catalogue could be presented. If they are to be discussed in some detail, only a negligible fraction of them can be considered at all. Furthermore, the life time of many chemical processes is only ten years and it is estimated that about half of the products of the major chemical companies is manufactured by processes which are less than ten years old.[1,2] Much of what can be taught in a descriptive course on technology is therefore obsolete already ten years later. The introduction of the concept of unit operations was a substantial progress over the older classical technology and much contributed to give chemical engineering its modern shape.

However, with time, the number of unit operations has quite increased, now there are about 30 to 50 of them which are of some practical importance. This called, in the education of chemical engineers, for a further step on the path toward generalization and toward a deeper process analysis, which can be achieved, however, only by escalating at the same time the abstraction. Since the fifties there is an increased tendency to reduce the processes to the fundamental physical and physicochemical phenomena involved. In the university curricula this is reflected by a strong emphasis on the teaching of the basic principles. In this approach more than ever the pillars on which the whole structure of chemical engineering rests are: thermodynamics (including energy and mass balances), transport phenomena (mass, heat and momentum transport), reaction kinetics and material science, together with sufficient mathematical support. These disciplines provide a very general background, whose validity is completely independent of any particular process, or any unit operation, and which allows one to attack any chemical engineering problem by a very basic approach. The knowledge of these disciplines is prerequisite for the sophisticated process analysis which is one of the principal aims of modern chemical engineering. Such an analysis is rather laborious, but once it has been carried out it allows one to master the process quantitatively and to predict numerically how changing the one or the other variable will effect the process. This may involve very complicated calculations but in the computer age this is no longer an unsurmountable obstacle. The computer has indeed provided the chemical engineer with a most powerful tool which enables him to manage numerically mathematical problems, the solution of which would have been perfectly hopeless only ten or twenty years ago. Of course, this presupposes a solid training in mathematics, especially in numerical methods, and in most curricula of chemical engineering the requirements in mathematics have been indeed substantially increased during the last decades. One of the reasons why the mathematical problems which the chemical engineer is facing are so difficult is that he must in fact deal with the

* Figure for 1964.

whole process, and not only with the single parts, i. e. the intricate interaction of the various parts of the process must be taken into account. The analysis of the process is the starting point, but in order to be really useful it must be followed by a synthesis in which the process is considered as a whole, with the complicated interplay of the various steps involved. The Chemical Engineer is dealing with a system, which should be in as much as possible automatically controlled and optimized. A modern chemical engineering curriculum should therefore include some training in system engineering, automatic control and optimization. Indeed, the ultimate aim is to optimize the whole process, in general with respect to cost. This economic aspect should be stressed. Although the modern approach, as outlined above, is a very scientific one and has opened what has been called the era of chemical engineering science, it should not be overlooked that economic considerations will always be of primary importance for the chemical engineer. In a sense, it can be said that chemical engineering is the combination of the laws of physics and physical chemistry with the pounds and the pennies.

It is now time to turn toward the situation on the European continent and to confess to you that until now in most continental countries there has been no true chemical engineering, at least not in the Anglosaxon sense. It is thus quite bold of me to have spoken for quite a while about the evolution of chemical engineering, of all places here in Newcastle, with its famous school of chemical engineering. Besides, I felt in the most true sense of the word, like bringing coals to Newcastle or, as the German expression goes, to bring water to the Rhine. So let us now discuss the past and present trends in Europe, more particularly in central Europe.

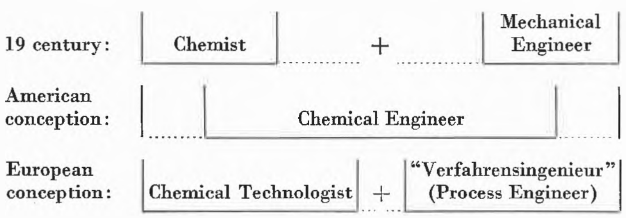


Fig. 3. Range of Disciplines Required to Develop a Chemical Process from Laboratory Scale to Commercial Operation

4. The European Pattern (Fig. 3)

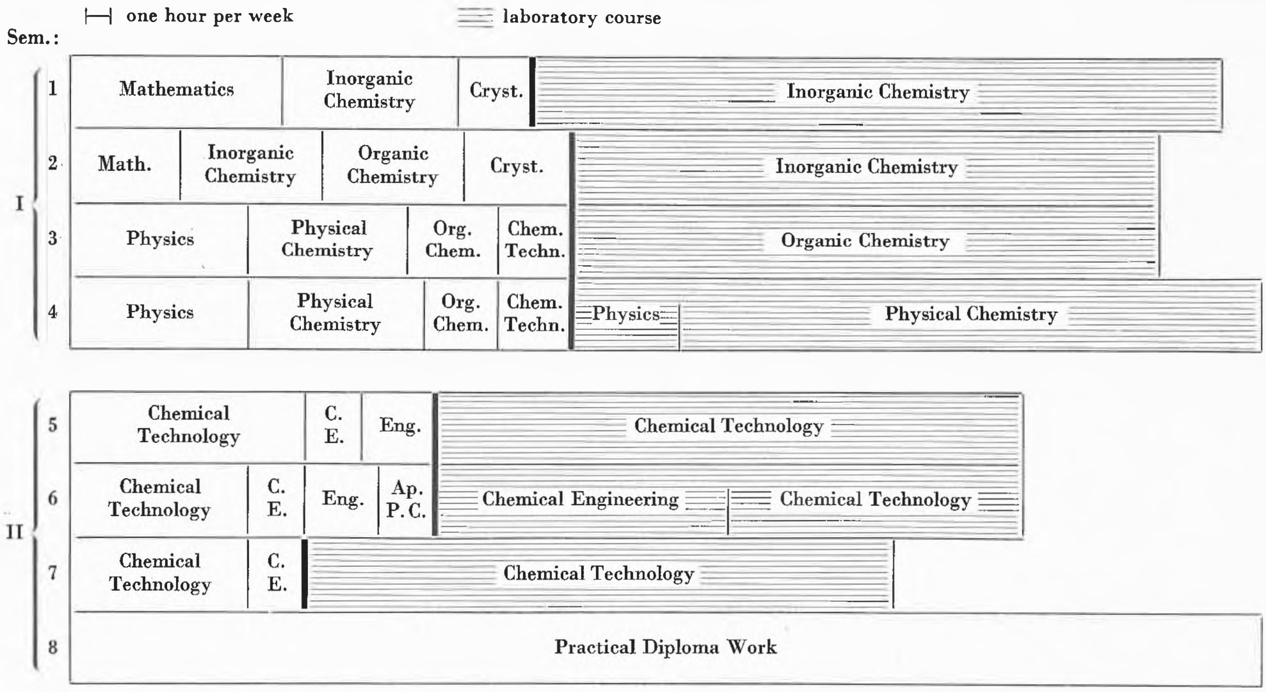
Having briefly reviewed the development of chemical engineering in America and Great Britain from about 1920 until the present time, let us now return to the period following the first world war, when it was more and more recognized that teams consisting of chemists and mechanical engineers did no longer work efficiently. As we have seen, in America and England, it was decided early that the equation:

chemist + mechanical engineer = chemical engineer

is basically wrong and that chemical engineering should be established as a discipline of its own right, comparable to electrical or mechanical engineering. In most European countries, however, no such drastic conclusion was made, at least not for many years to come. It was believed that the equation: chemist + mechanical engineer = chemical engineer, was essentially right, and that all it needed to make it hold true was a correction of not too great importance. It was felt that the gap of understanding between the chemist and the mechanical engineer could be bridged if the technical universities would produce a chemist with some additional knowledge of chemical technology and mechanical engineering on the one hand, and a mechanical engineer with some additional knowledge in chemistry and physical chemistry on the other hand. The first one is usually called a chemical technologist, the second one a "Verfahrensingenieur", the best English translation of which is probably "process engineer". It was felt that the team of these two professional men would be equivalent, and in some circumstances perhaps superior, to a specially trained chemical engineer. It may be noted that the situation in France does not fit into this scheme because the best known engineering schools of that country such as the Ecole Polytechnique or the Ecole des Mines concentrate on a very general, strong training in mathematics and physics, the specialization in a particular branch of engineering taking place only after the student has left the school, and until recently there was little opportunity to specialize in chemical engineering. The pattern sketched above applies in the first place to Germany and some other middle European countries, including, by and large, Switzerland. It has remained essentially the same until now. It is true that over the years an evolution of the curricula has taken place, as it has been also the case for the chemical engineering of the English speaking countries. The courses on technology have become less descriptive, elements of chemical engineering, mainly unit operations, introduced and some courses on applied physical chemistry have been added. On the other hand, in the curricula on "Verfahrenstechnik" more time than before is devoted to certain fundamentals of chemical engineering, such as transport phenomena. But, by and large, the "Verfahrensingenieur" has remained essentially a mechanical engineer, the technologist has remained essentially a chemist. A typical study programme of a chemist specializing in technology and engineering consists of laboratory courses (mainly chemistry) for half of the available time (Fig. 4).

5. Outlook for European Chemical Engineering

We have seen that the pattern of education designed to meet the requirements of the chemical industry was quite different on the continent and in the English speaking countries. It may be noted at this point that,



I: together with Chemists
II: Specialization as "Ingenieur-Chemiker"

Abr.: C.E. = Chemical Engineering
Eng. = Engineering ("Maschinen- und Apparatelehre")
Ap. P. C. = Applied Physical Chemistry

Fig. 4. Curriculum at Swiss Federal Institute of Technology as of 1967

in spite of their differences, both systems have been quite successful and appear to have both accomplished what was expected of them. However, presently, there is much discussion about whether the traditional continental pattern should not be more or less deeply modified, some changes are already taking place and more of them are planned or envisaged. Indeed, we should prepare our students for tomorrow, but the world around us is changing so fast that we have doubts whether we are not preparing them only for today, or may be even only for yesterday. The changes are taking place at a breathtaking pace and it is hard to predict with any reliability what tomorrow will look like when today's students are in the middle of their careers. This is a problem which we are presently facing with many university or high school curricula and it is probably the reason why there is in most countries so much discussion now about changes in curricula and in the organization of the universities. Chemical engineering makes no exception. Switzerland and Germany are, in this respect, now in a stage of transition. They are still searching their way.

Before we discuss the present trends, it is worth wile to analyze briefly first why two different patterns for the education of chemical engineers, or their equivalents, have evolved on the continent and in the English speaking countries, and why both systems have been successful. The reasons which can be given (and quite particularly the question whether they will remain valid for the future), have of course a great influence on our thinking regarding the desirability or the necessity of reforms.

One important aspect is the structure of the chemical industry. During the period between the two world wars, the dyestuffs and pharmaceutical products were one of the main pillars of the chemical industry in Germany and Switzerland, for instance, whereas in the USA the oil refineries and the heavy chemical industry were relatively much more important. The Swiss chemical production, for instance, is relatively large in value (400 Million £ for a country with a population of 5 millions), but relatively small in tonnage. Its characteristic feature is a very great variety of products, most of which are manufactured on a rather small scale. Under these conditions the techniques employed are closer to those used in the laboratory than in the case of the heavy chemical industry, and batchwise operation prevails. A solid and broad chemical background is much more important than in a refinery, for instance, and the decrease of the overall cost which can be achieved by changes in the chemistry of the process, is often much more substantial than that which may result from a sophisticated engineering approach. It should also not be overlooked that for the detailed chemical engineering analysis of a process, which was mentioned earlier, the influence of a number of variables on the process must be established quantitiatively. Numerous parameters and physical properties of the substances, solutions etc. involved must be known. These data are usually not available and must be determined experimentally first. All this is very time consuming and when the analysis is completed, the advantage of being the first on the market may have been lost, or the process may have even become obsolete from the chemical viewpoint. Furthermore, and this is probably even more important, a refined analysis of the process is very costly and will in general pay off only if the turnover is sufficiently large. These are probably the reasons why teams consisting of chemists or technologists and "Verfahrensingenieure" have been quite successful in large areas of the European chemical industry so far. In fact, even in the USA, there has been recently a reaction against the strong emphasis, at most American schools, of what may be called the highly sophisticated scientific aspects of chemical engineering, and against the tendency to educate the Chemical Engineering Student as a pure scientist.[3] Quite a number of people in industry feel that too much importance is given to the analysis of processes at the expense of engineering disciplines or chemistry. It is claimed that a sufficient amount of factual knowledge both in engineering and chemistry is still important for successful work in industrial practice. The industrial systems are so complicated that a complete mathematical description is often hardly possible or too costly. For these reasons, in the USA, opinions have been voiced tending to reverse the present trend toward generalization and chemical engineering science, or at least to slow it down, the best solution being sometimes regarded as two curricula, the one emphasizing chemical engineering science, the other more orientated toward the engineering and process design aspects. The above arguments are particularly often advanced in countries with little mass production of chemicals, a small or no oil industry etc. They are undoubtedly justified, at least to some extent, and any reform of the curricula in these countries will have to take them into account by giving more weight to chemistry and chemical reaction engineering than in regions with a different industrial structure. Also, the knowledge of materials and of their properties, their corrosion etc., which can in many cases affect the economics of a process more than an advanced optimization of the operating veriables, should be probably more stressed than it is now done in most places.

But let us now turn toward the arguments which are presently put forward on the Continent for a decisive change in the training of the professional man who is needed for the industrial applications of chemistry. One of the important questions which arise here is whether, or not, the situation has now become substantially different from what it used to be while the traditional pattern was working fairly smoothly and, particularly, what is the situation likely to be in the foreseeable future. First, it should be mentioned in this connection that the impact of an ever increasing production is of course felt in Continental Europe too. Since the second world war many oil refineries and petrochemical plants have been put on stream and quite generally the heavy chemical industry is expanding fast. Switzerland, which used to import all its gasoline and fuel, has built pipelines and erected two oil refineries quite recently. Even in the dyestuff and the pharmaceutical branch the tonnages are now often quite important, especially for the intermediate products. The plastic industry has become one of the large producers beside the traditional ammonia and sulphuric acid plants.

Second, one may ask whether the application of the methods of chemical engineering, in its modern version, is really worthwhile only in the case of a large scale production. At the beginning I have particularly emphasized this aspect. But in fact, what is primarily important, is the value of the production rather than the tonnage. It is true that certain typical problems of chemical engineering do no longer play a major role when the product is a high priced one but the output is small. The energy consumption, for instance, or the optimization of the pipe network become of little consequence. The knowledge of heat transfer or of hydrodynamics is of less importance when one is dealing with what is sometimes called in Switzerland the "Feinchemie". In electrolytic aluminium production, for example, a decrease of the power consumption by a few tenths of a kWh per kg of aluminium produced is a big success whereas in the electroplating industry a similar saving is irrelevant. But, in principle, the general techniques of chemical engineering will be applicable irrespective of the size. There is a certain attitude of the mind, a way of thinking and method of approach which are characteristic of the chemical engineer but quite unfamiliar to the chemist and which are of great importance in the industrial applications of chemistry even if the tonnages involved are small and the operation batchwise. The concepts of Chemical Reaction Engineering supplies the techniques needed to optimize the yield of highly valuable chemicals. Automatic control may be most beneficial not only to save labor costs which would too much burden the economy of the manufacturing of a cheap substance, but also in order to obtain a product of high and uniform quality. An important aspect which is independent of size is the system engineering approach. It has already been pointed out that a chemical process involves usually many steps which interact with each other in a more or less complicated manner. The plant can be regarded as an organism or a system, the various parts of which must be well integrated so that the whole works smoothly. The dynamic response of the various parts (and of the whole) to changing conditions must be well under control. Ideally, the system should adapt itself automatically to changing input (or other) conditions in such a manner that optimum performance is always maintained. In this sense chemical engineering reaches into the wide field of system engineering and cybernetics. At various places this aspect of chemical engineering is presently much emphasized. Obviously, the problems involved here do not depend on the scale, only the value of the return should be worthwhile the effort. This speaks in favor of the introduction of chemical engineering curricula of the Anglosaxon type even in countries with little heavy chemical industry. An interesting example where the value of a system, and not its size, justifies an advanced analysis is biomedical engineering. Chemical engineering will have an important word to say in this new field[7,8] and may even include it as a special branch. Recently, at a well known american school of chemical engineering the complete design and optimization of an artificial kidney has been taken as class work for a whole term and this venture has been extremely well received by the students. In fact, any living being is a most remarkable system in which complicated chemical and physicochemical processes are amazingly well coordinated. Some say it is the result of competitive evolution, others say it is the achievement of a Super Chemical Engineer. But it certainly is a system, and, from the viewpoint of system engineering or chemical engineering, by far the most sophisticated one we know.

However, nature usually solves its engineering and chemical engineering problems with techniques which are very different from those which we are using. It ignores the classical separation procedures of the chemical engineer such as distillation, crystallization and filtration. But we may note as a paranthesis that at present, in some instances, chemical engineers start using methods similar to those of nature. Membranes, the typical separation tool of nature, are the decesive operating factor in electrodialysis and inverse osmosis which are presently studied with the aim to desalinate sea water and which are, at least to some extent, already used in practice for that purpose. Quite generally the development of new more efficient and economic separation methods is an important target of chemical engineering research. The desalination of sea water and the treatment of waste waters are examples of two challenging problems which lie ahead and where cheap solutions must be found. Especially the second of these two is becoming more and more of paramount importance for most European countries.

The two aforementioned problems illustrate the broad scope of chemical engineering which is another important factor to be considered in the discussion of the future evolution of European chemical engineering. Also the example with the artificial kidney has shown us that there are indeed areas which may seem at first sight unrelated but where typical chemical engineering problems such as mass transfer, fluid flow and separation of mixtures play an essential role. The scope of chemical engineering is in fact much broader than the chemical industry proper. The general techniques of chemical engineering are also encountered in the food processing industry, in nuclear power plants, in the separation of isotopes, in extractive metallurgy, in mining, in the cement industry, and many chemical engineers are indeed employed in these branches of industry.[5] The huge isotope separation plant of Oak Ridge could never have been built up so rapidly during world war II, if America would not have disposed at that time of a great number of well trained chemical engineers. The conception of chemical engineering as a broad discipline is popular today and seems very pertinent. A broad definition is as follows: Chemical engineering involves all processes which change the composition or properties of matter in bulk. With this definition chemical engineering embraces a very large area of our industrial and human activities. It has been estimated that in Germany, for instance, about 30% of the whole industrial output is connected with processes which belong to chemical engineering.[1,4]

It is its broad scope and the great variety of its problems which makes chemical engineering so challenging and so attractive. But it makes its teaching very difficult, because it is hard to decide which subjects should be stressed. Although the chemical engineer should be an excellent specialist, he must strictly avoid the characteristic feature of the modern specialist who has an immense knowledge, but only in a very narrow field, and who has been defined as someone who knows everything about nothing. At the same time the training of the chemical engineer must be an effective one, he must be able to solve complicated concrete problems and cannot afford to be like the universal genius of the past, who knew nothing about everything.

It seems that the best way to prepare him for his broad range of activities is to emphasize, in the education of the chemical engineer, the teaching of the fundamental subjects: mathematics, physics, physical chemistry, transport phenomena and principles of chemistry. There is indeed a strong tendency in this direction today. There is at many universities the justified feeling that only generalizations constitute knowledge which is really teachable whereas the teaching of this or that detail of a process is only the passing on of today's art. Concentration on the basic disciplines gives us also the best chance to teach something which will remain valid in the future in spite of a rapidly changing world. Stressing the fundamentals, especially the physical ones, appears justified by the fact that so much physical thinking is involved in chemical engineering already now and this is likely to be even more so in the future. During the last decades there has been indeed a continuous shift in the same direction: What used to be physical chemistry is now chemistry or chemical engineering, what used to be physics is now physical chemistry. This also applies to technology. It has been said that the physics of today is the technology of tomorrow.

In view of the broad scope of chemical engineering and the emphasis on the physical and physicochemical aspects one may wonder whether the term "chemical engineering" still adequately describes this discipline as it is usually concieved today. Various authors have proposed to call it "process engineering" instead.[6] Semantically at least it thus gets very close to Germany's "Verfahrenstechnik", the best translation of which is process engineering. But there may be soon more to it. Traditionally "Verfahrenstechnik" has been essentially only an extended version of mechanical engineering. But the present trend is to introduce into the curricula more and more chemistry and chemical engineering subjects, such as transport phenomena, at the expense of more classical engineering disciplines. The new technical faculty of the University of Erlangen is now building up a Department of Process Engineering with a separate two years curriculum on top of a two years training either as chemist or engineer. The Department will closely cooperate with the Department of System Engineering and with a strong Department of Material Science. One or two other German Universities have similar plans. This scheme may still be somewhat different from the Anglosaxon one. But, by and large, if the present trend continues the differences between the Anglosaxon and the continental pattern will tend to fade and a more unified concept will eventually emerge. This does not mean that different countries may not develop different shades of chemical engineering, adapted to the *genius loci*. For instance, in a country with much "Feinchemie" chemistry will certainly be an important subject in the curriculum of chemical engineering. But, by and large, the tendency seems to be that the continental pattern is getting closer to the Anglosaxon concept. Whether it is fortunate or not, the contemporary world, with its easy travelling, its easy communications of ideas and goods, tends to level out the differences which formerly existed in the way of life and in the way of thinking between the countries, and it seems that chemical engineering is going to follow the general trend.

Acknowledgement. I wish to thank the Marchon Company, England, fot its grant and for the invitation to deliver the 1968 "Marchon lectures" at the University of Newcastle.

Schrifttum

1. P. Grassmann, *Physikalische Grundlagen der Chemie-Ingenieur-Technik*, S. 27–30, Sauerländer, Aarau 1961, Band I der Grundlagen der chemischen Technik, herausgegeben von H. Mohler und O. Fuchs.
2. R. Söhngen, *Chem.-Ing.-Techn. 31* (1959) 175.
3. W. R. Marshall, Vortrag am Jahrestreffen 1965 der Verfahrensingenieure, Nürnberg; O. A. Hougen, Chemical Engineering Education in the United States, *Lecture presented at London Joint Meeting A. I. Ch. E.-I. Chem. E., June 17, 1965.*
4. K. Riess, *Chem.-Ing.-Techn. 30* (1958) 696.
5. P. Grassmann, *Schweiz. Bauztg. 78* (1960) 31–6.
6. K. Rietema, publication of *La communauté européenne culturelle des étudiants en chimie:* The Growth of a New Engineering Branch, Process Engineering.
7. P. Grassmann, *Chem.-Ing.-Techn. 21* (1967) 1217.
8. E. Guccione, *Chem. Eng. 1967*, 94–6, 107–24.