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CHEMICAL ENGINEERING EDUCATION AND RESEARCH IN GREAT BRITAIN*

By Prof. W. E. GIBBS, D.Sc.

The chemist works in a laboratory, whereas industry operates on a grand scale. The problems and difficulties that arise in a works are entirely different from those that are encountered in the laboratory, so much so that many a promising laboratory process has proved to be completely unworkable on an industrial scale. Let us consider some of the conditions that affect the planning of an industrial chemical process.

We will assume that the necessary raw materials and reagents can be obtained at a reasonable price, in adequate quantities, and of a sufficient degree of chemical purity. Large quantities of them have to be stored, prepared, and transported through the successive stages of the process. All the plant and containers that are to be used, as well as the actual reaction vessels, must be made of special materials so that neither the yield nor the quality of the finished product shall be impaired.

The heating or cooling of a large reaction mass is beset by peculiar difficulties requiring for their solution an intimate knowledge of the laws of heat transfer and of material flow.

The efficient separation of the desired product from associated materials, and the final preparation of the pure product for the market call for specialised knowledge as well as constant thought and ingenuity.

Throughout the whole range of operations the quantities of the materials employed must be measured accurately. Temperatures and pressures must be kept within well-defined limits.

The necessary heat, power, and water must be supplied. Adequate skilled and unskilled labour and supervision must be provided.

Finally, everything must be done with one end in view—an adequate return upon capital.

These are some of the problems whose study properly belongs to the newly developing science of chemical engineering. For chemical engineering is a distinct and separate branch of science with its own problems, its own methods, and its own opportunities. It is concerned primarily with the quantitative and economic study of the various unit operations, *e.g.*, grinding, roasting, mixing, dissolving, filtering, evaporating, distilling, crystallising, drying, etc., which in their proper sequence make up a chemical process on an industrial scale. It differs from applied or industrial chemistry, which deals generally with processes and products.

Some of the matters with which the chemical engineer is peculiarly concerned are: the flow at different temperatures and pressures of fluids and semi-fluids differing widely in viscosity and density and in chemical and physical stability; the efficient heating and cooling of large quantities of widely different materials; the control of large-scale chemical reactions; the design and operation of unit types of chemical plant to work under all sorts of conditions; the chemical and physical testing of the materials that are used, or might be used, in the construction of chemical plant; the production of new structural materials suitable for special duties; the design of entirely new types of plant; the investigation of a number of important problems that beset chemical production in a multiplicity of forms, *e.g.*, the formation of scale upon heating surfaces, the corrosion of metals, the control of crystallisation from gases and liquids, the efficient disintegration of solids and liquids, the efficient use of catalysts.

In the nineteenth century the widespread application of machinery and mechanical power to industrial processes created a demand for men who were specially trained to understand the operation of these apparently highly complicated mechanisms. The peculiar usefulness of the engineer lay in his acquired facility for visualising an apparently complicated machine as a closely-related series of individual operations each of which was simple in itself and could readily be understood.

Every scientific man acquires this faculty of being able to see below the surface of his material and resolve an apparently complex structure or activity into its simpler constituents.

To a chemist a chemical reaction between two or more substances is an incredibly active dance in three dimensions, in which myriads of each kind of elementary particle, or atom, concerned are engaged. Provided the conditions remain unchanged the dance may go on for ever without any appreciable exchange of partners. But let the temperature be raised or lowered, or let the pressure be increased, or let some other substance be introduced, it may be only a trace, and the original partnerships become dissolved and others are formed. New compounds are obtained.

An industrial chemical process is at heart a chemical reaction, but the reaction is hidden away in an elaborate arrangement of plant and machinery. The engineer can generally fathom the meaning of the machinery, but the reaction baffles him. The chemist can understand the reaction if only he can find out where it is going on. Neither understands the complete process, nor can they together grasp it completely. For there are many difficulties in an industrial chemical process that only arise when the work of the chemist and the work of the engineer are brought together.

It has become necessary, therefore, to train men who

* Public Inaugural Lecture by the Ramsay Professor of Chemical Engineering, delivered at University College, London, on Dec. 3, Sir Robert Waley Cohen in the Chair.

shall be able to see the process as a whole, not only as the chemist and the engineer see it, but also as they do not see it. This is the function of the chemical engineer.

An industrial chemical process should be worked out in the laboratory by the chemist. A chemical engineer should then design the necessary large-scale plant and the engineer should erect it. When all is ready the plant should be tuned up and operated by a chemical engineer. Unfortunately, owing to the present lack of trained chemical engineers, many plants in this country are designed and operated by men who have been trained as chemists or engineers. Consequently, the efficiency of the whole process frequently suffers to an extent which varies according to the nature of the process and the personal peculiarities of the chemists or engineers concerned.

There are, of course, even to-day many instances in which the chemistry of a process is so simple or the mechanical contrivances required are so familiar that the design of the necessary plant is relatively simple, and can safely be entrusted to a chemist or an engineer. But in most modern processes, and to an increasing extent with the development of new synthetic processes, chemical plant should be designed and operated by men who have been trained in the principles and practice of chemical engineering.

Further, it is only by the intensive scientific study of each unit operation, and of those factors upon which its efficiency depends, that we can expect to obtain any real improvement.

A chemical engineer cannot be produced satisfactorily by the time-honoured process of training him as a chemist or as an engineer, and then putting him into a chemical works to develop. There are exceptional instances, of course, of men who, because of unusual opportunities or as the result of a long apprenticeship, have developed in this way into exceedingly able chemical engineers. But in the ordinary way the method is slow in its development and uncertain in its results.

Let me try to express graphically what I mean. We will regard the chemical engineer as made up of two components, the chemist and the engineer. Depending upon the extent to which these two components are blended in his make-up he will possess a certain capacity for overcoming the peculiar difficulties that will confront him in a chemical works. Let us plot his "softening point" when exposed to these difficulties against his composition.

The softening point of a chemist is probably somewhat lower than that of an engineer at the outset. As he gains works experience and absorbs some engineering knowledge it rises, rapidly at first and afterwards less rapidly as his immediate needs become satisfied.

The softening point of the engineer, although higher than that of the chemist, does not rise quite so rapidly as a result of his works experience. As a rule he is not so much in need of chemical knowledge as the newly graduated chemist is of engineering knowledge.

The degree of difficulty varies widely for different chemical operations. We can express it as a series of horizontal lines drawn across our diagram. Some of these lie just above the softening point of the pure chemist. Others are well above that of the chemist, but only just above that of the engineer. These are the comparatively simple operations involving either little chemical or little engineering dexterity. A chemist or an engineer can generally cope with them successfully after some experience of plant conditions.

For most processes, however, the degree of difficulty lies well above the softening points of both the pure materials. In some industries the softening point curve has already risen high enough to provide the necessary degree of ability. In most cases, however, the degree of difficulty lies well beyond the softening point of any of the mixtures that we have yet produced, and the level is rising. We have to obtain a product that will be able to rise superior to the difficulties, however high they may become.

I cannot help feeling that this degree of ability will not be possessed by any kind of mixture. Long contact with works conditions may burnish such a mixture and produce a kind of superficial hardness. But when the testing time comes the softer material lying underneath the skin will give way and let the whole thing down.

What is needed is a definite compound made up of these two constituents, but with their distinctive properties so modified by their combination that it is to all intents a new and distinct product endowed with peculiar characteristics. Emphatically it would be very much harder than any mixture of the components could ever be.

The problem confronting us to-day is to find the composition of this compound, and then to discover how to make it on a large scale.

The universities at present are manufacturing the pure products, and are doing it exceedingly well, but little is being done by the universities to produce the desired compound—the chemical engineer. Probably this is because they do not yet know its precise composition, and therefore do not know what to make.

Let us consider the properties of the chemical engineer and try to deduce his composition. We may then be able to work out a suitable method of manufacture.

My predecessor in this chair, Dr. E. C. Williams, to whom the cause of chemical engineering education owes so much, has defined a chemical engineer as a "scientific man whose duty it is to plan the large-scale commercial operation of chemical processes and to design and operate the plant required for the carrying out of the chemical reactions and physical changes involved."

Every chemical process is at heart a chemical reaction between dissimilar atoms. The success or failure of the process depends primarily upon the direction in which the reaction goes, and also upon the extent to which it can be completed. The chemical engineer, therefore, must be familiar with the chemical reactions involved and able to appreciate fully the physical and chemical conditions that are essential to the successful working of the reaction.

He must also be able to visualise the complete process as it is to be carried out in the works. He must plan the arrangement of the plant, prepare a quantitative flow sheet of materials and energy, and draw up a costs analysis. He must prepare lay-out drawings, draw up complete specifications for the purchasing of standard plant units by the purchasing department, and make complete drawings of any special plant that may be required. He should select the necessary skilled and unskilled labour, and organise the starting up and the continued operation of the process. Finally he should work out the running costs and prepare a complete process specification.

Since it is essential above all else that the chemical engineer should be intimately acquainted with the chemical reaction, I think that he should be primarily a chemist. He must be sufficiently familiar with the principles and practice of engineering design and draughtsmanship to be able to tell the engineer in the clearest possible terms exactly what he wants. He must understand the construction and operation of all the plant and machinery, otherwise he would be unable to plan or design or direct the operation of the process.

He will not have to carry out the original research. That is done by the chemist. Nor does he construct the plant. That is done by the engineer.

The chemical engineer should be the director of the complete series of operations. He should receive from the chemist the results of his work and make them available for the engineer who is to construct the plant. He should superintend the erection of the plant and ultimately direct its operation.

In so far as it is possible to state the composition of the chemical engineer in terms of chemistry and engineering, I should expect to find him consisting of about 70% chemistry and 30% engineering.

It must be admitted at once that this ideal chemical engineer is not being trained in any of our universities to-day. A very promising start in the right direction has been made here at University College and also at the Imperial College of Science and Technology. At each of these places an attempt is being made to convert a chemist or engineer, after he has been formed, into a chemical engineer.

In the Ramsay Memorial Laboratory of Chemical Engineering, at University College, graduates in chemistry or engineering are given courses of lectures in heat transmission, the flow of fluids, the production and distribution of energy in chemical works, the design and operation of unit types of chemical plant, the physical and chemical examination of materials used in chemical plant construction, and the preparation of quantitative flow sheets and balance sheets for materials, energy, and cost in industrial chemical operations.

These lectures are supplemented by experimental work in the specially-equipped chemical engineering laboratories. During the summer term and the long vacation students may spend the whole of their time in chemical works, either to gain experience of works practice or to investigate some chemical engineering problem on a manufacturing scale.

A chemist and, to a less extent, an engineer who has taken such a post-graduate course in chemical engineering can go into a chemical works and tackle its peculiar problems with intelligence and insight. He will not have to spend the greater part of his first year learning to acquire " plant sense." He will know how to handle his materials in large quantities in the most convenient way and with the least expenditure of labour. He will be able to visualise the most complicated process as a logical sequence of well-defined unit operations. He will be familiar not only with the design and operation of the different types of plant that have been developed for carrying out these unit operations, but also with the underlying scientific principles upon which their design is based. He will therefore be able to apply these principles to the design of entirely new types of plant that may be necessary for some new process or set of conditions. He will be fully alive to the quantitative and economic significance of all the work that is done at each stage of the process. He will realise the importance of carrying out the work profitably, even if, in certain circumstances, it may be at the expense of chemical efficiency. Finally, he will not only be able to operate a process efficiently, but he will also be well able to investigate the peculiar problems that arise so frequently during its operation.

Such a man, when he enters the industry, should be able to develop into a thoroughly efficient chemical engineer. He should be worth much more to his employer, other things being equal, than a man who has not had such training. For from the beginning he will develop his full output of usefulness more rapidly than the other, and will continue to be more useful at every stage of his career whatever the work that he may be given to do. It is therefore to the direct advantage of the employer to do all in his power to encourage chemical engineering education in this country.

He can do this in several ways. He can insist upon a certain proportion of his new men being trained chemical engineers. He can send members of the staff who have been trained as chemists or engineers to spend a year or so taking the existing post-graduate course at the Ramsay Laboratory or at the Imperial College. This would be a most valuable experience for a man who, having already spent two or three years in a works, knows the kind of problems that he has to solve.

The employer can gain a great deal by co-operating more closely with the universities. The universities exist to meet a demand, and if only the employer knows what he wants and states it clearly enough, and also, if necessary, is prepared to contribute something towards the cost, he will get it. There should be a post-graduate course in chemical engineering at every university at which there is now a strong school of chemistry. Promising students should be encouraged to qualify as chemical engineers, for the industry can probably do with fewer chemists at present if only it can get more chemical engineers.

Ultimately, there should be complete undergraduate courses in chemical engineering in which both chemistry and engineering would be taught from the chemical engineering standpoint. Meanwhile, it should be possible to introduce the chemical engineering viewpoint more frequently into the present teaching of chemistry and engineering. The chemist could well be taught something of the power and energy requirements of a chemical process, the transfer and conservation of heat, and of the design and operation of certain unit types of chemical plant.

The engineering course in hydrodynamics might be extended to include viscous fluids and slurries. In the course dealing with the strength of materials some account might be given of the chemical and physical properties of some of the special materials that are used in the construction of chemical plant.

Valuable and stimulating experience can be gained from visits to chemical works preceded by lectures, in which the important chemical engineering features of the plant are discussed.

All this would help to introduce the student to the chemical engineering point of view as distinct from the purely chemical or engineering one. It would provide a background against which a more complete presentation of chemical engineering principles and practice could be constructed in one of the existing laboratories that are devoted to the subject.

Finally, a few words about the equally important subject of chemical engineering research. It is often impossible to design a satisfactory plant because the necessary chemical engineering data are partially or completely lacking. Little is known, for example, about the physical and chemical behaviour of new structural materials or of old materials under new sets of conditions, *e.g.*, at high temperatures and pressures. We have fairly reliable overall coefficients of heat transfer through many materials, but next to nothing is known of the heat transfer coefficients of the different films of which the complete dividing wall is invariably made up. We cannot estimate with any degree of accuracy the power that is absorbed in transporting powders such as powdered fuel through pipe lines. We know very little about the formation of crystals from gases and liquids, or the flocculation of fogs and smokes, or the adsorption of vapours, or generally about the behaviour of colloidal substances in large quantities.

Much of this information is needed now if certain kinds of plant are to be designed in a scientific manner. But who is to obtain it? The chemical plant manufacturer, too often, is not equipped for this kind of work. Frequently he does not consider that it is in any way his business. The research chemist and the research engineer have attacked some of these problems, but generally from a purely chemical or engineering standpoint, so that their results are not directly applicable to plant design.

Well organised, systematic chemical engineering research should be as much the business of the chemical industry and of the government of this country as purely chemical or engineering research is at present. A beginning can be made, and is being made in the university laboratories that are devoted to this subject. But the work must be prosecuted on a very much larger scale if the chemical engineer is to keep pace with the present rapid development of pure research, and design the plant that will be necessary for its effective industrial realisation. Chemical employers and chemical plant manufacturers might well consider whether they cannot promote chemical engineering research either by providing for it in their own laboratories, or by endowing research fellowships in the universities either for the determination of fundamental data of general importance to the industry as a whole, or for the elucidation of some problem which may concern their immediate business.

In conclusion, I would emphasise that the need for chemical engineering education and research in this country is clear, is vital, and is urgent. In other countries—America, Germany, Holland, France—the value of chemical engineering education has long been recognised. This is one reason why so much of our plant is still obtained from foreign sources—why many branches of chemical industry became firmly rooted abroad before they were established here.

I foresee a future in which the chemical engineer will be a dominant force in the industrial life of this country. Because of his comprehensive grasp of all the essentials of his trade he will become both clear and far-seeing, so that all men will come to look to him for inspiration and leadership. Under his direction the industries of this country will become the most efficient in the world.

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