THE AIMS AND FUTURE WORK OF THE RAMSAY MEMORIAL LABORATORY OF CHEMICAL ENGINEERING

Inaugural Lecture at University College, London, January 17, 1924

(Sir ROBERT ROBERTSON, K.B.E., D.Sc., M.A., F.R.S.
IN THE CHAIR)

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THE AIMS AND FUTURE WORK OF THE RAMSAY MEMORIAL LABORATORY OF CHEMICAL ENGINEERING

THE address which I am to give this evening marks the embarkation of this College upon a new venture, the results of which, we hope, will cement still more firmly the bond which already exists between it and the industrial life of the country. To you who have the interests of the College at heart and to those of you who are more particularly concerned in what the College can do for the growing chemical industries, it is my privilege to explain what our plans are and what we hope to achieve in the new Ramsay Laboratory.

Though this step has been under consideration for some years, the occasion comes opportunely at a time when great interest—not to say controversy—is being shown, in many different directions, in the need for chemical engineers and the training which they should receive.

The conviction that there is here a field calling for special attainments on the part of the men who enter it has shown itself in professional circles in the recent formation of the Institution of Chemical Engineers, an institution which, by maintaining a high level of attainment and co-operation amongst its members, has it in its power to render inestimable service to its members and to the industries which they serve. The University College has, in founding this department, shown itself not unmindful of the part which it can play in this development. This part must by the nature of things be different from that of the Institution. We have the special advantages which the freedom of University conditions confers, we have also certain disadvantages. We cannot in the time at our disposal, or under the conditions under which we work, attempt, nor would it be making the most of our opportunities if we tried to attempt, to turn out a completely equipped professional chemical engineer, any more than we can give a man in one or two years that invaluable commodity—experience. We can, however, lead men who have completed their scientific training and have acquired a knowledge of scientific facts and methods and theories to see how that knowledge can be brought to the service of industrial operations, and we can amplify the training they have already received along those lines which will fit them to take their place more efficiently and with greater hope of success in any industry to which they may eventually be called.

I cannot, however, pass on to my subject without referring to the fact that by the inauguration of this department we are primarily commemorating the life and work of a great man, pre-eminent amongst scientists, whose memory is cherished within these walls for the lustre which his personality and achievement have added to them. Ramsay was, if one may for an instant apply a hyphenated title to such a man, a physical chemist and not a chemical engineer, but that fact alone is full of significance to us.

No department could ask a greater honour, nor a more auspicious augury, than that it should bear the name of Ramsay. It is an honour which we of the department and our successors will ever greatly treasure.

In view of much that has been said and written within the last few years on the subject of chemical engineering, I think it is advisable that I should start with some definition of what we consider a chemical engineer to be. The question has been put so frequently that I do not think I can at all assume that we all stand upon the same ground. The field is so vast that it will in any case be difficult to give any definition which is reasonably succinct and which at the same time expresses the full extent of the field in which the chemical engineer will be called upon to work. I regard 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.* This is rather different in form from the definition adopted by the Institution of Chemical Engineers, but it introduces nothing which the latter does not imply, and I use it here because it stresses the planning of the operation itself as well as the actual design of plant. I do so because, after all, the main purpose of the chemical engineer's work is the efficient operation of chemical and physical processes and the plant employed is, though of vital importance, only a means to an end. The correct design and efficient working of a chemical plant are the outward and visible signs of the chemical engineers' appreciation of the chemical and physical phenomena with which he deals.

Taking this definition as our starting point let us consider whether there is any field of which we can say—“ this is peculiarly the province of the chemical engineer, as distinct from that of the chemist or that of the civil or mechanical engineer.

Do not misunderstand me when I say distinct from. I do not intend to convey for one moment that the chemical engineer can separate himself into a class apart from the chemist or from the engineer. He will need all the tools of the chemist and many of those of the physicist and engineer also if he is to be able to work in and to develop his own particular field. What we have to consider is, rather, whether there is any such limitation or expansion of the field, any new ground to be broken, which demands special knowledge or special training, or a special outlook, different from that of the pure chemist or engineer, and, if so, what that outlook is, and how it is to be developed.

Some conception of the variation of opinion on this question is well illustrated by a recent article which stated that the duty of a chemical engineer was

(1) To design and erect buildings;
(2) To provide any power that may be required;
(3) To design if necessary and erect the plant to the instructions of the chemist;
(4) To superintend maintenance and repairs;
(5) To possess common sense and a general acquaintance with chemical nomenclature;

and naïvely continued "that none of these duties required any exceptional knowledge or attainments." One is tempted to wonder how many would care to entrust their chances of longevity to the tender care of a surgeon whose duties were to provide ether as required, to design and carry out operations to the instructions of, say, the bacteriologist, to possess common sense and a general acquaintance with medical nomenclature.

The writer of that article had in mind a most necessary and invaluable man, but I think most of us would call him the general works or maintenance engineer, or, in a small works, the foreman fitter. Emphatically a most invaluable man and, I willingly agree, often more skilled in some of the problems of chemical engineering than many chemists. But I suggest to you that the great majority of chemical industries are looking for something more than that; very few chemists, as chemists are at present trained, are able to give those instructions upon the design of plant to which the writer refers (if they were they would be well on the road to becoming chemical engineers), while the works engineer certainly has not got the knowledge to make good what the chemist lacks.

In the course of years a chemist, whose outlook is sufficiently broad and who has the initiative to apply his scientific training to the innumerable problems which present themselves in the operation and design of industrial plant, should become a first-class chemical engineer. The same applies to the engineer who will endeavour with sympathy and understanding to grasp the fundamental ideas and see through the eyes of the physical chemist.

The chemists who achieve this are few and proportionately valuable. The engineers who achieve it are fewer still, because they have the more difficult task of acquiring the view-point of the chemist.

The two primary factors which differentiate the field of the chemical engineer from that of the academic chemist are the increased scale of operation and the necessity of working commercially—that is, for profit. I omit for the moment the question of compatibility of the materials of which the plant must be constructed; this too is an all-important factor, but is not so fundamental in its effects and is a consequence of either one or other of the two primary factors I have mentioned.

Do these two considerations, scale and profit, introduce any such degree of novelty into the operation of chemical processes, that we are justified in considering the type of knowledge and training required by the chemical engineer to be something different from that of the chemist ?

Dealing first with the question of working for profit—and this is the *sine qua non* of all industrial operation—I would like to make one point very strongly and very clearly for those who are leaving the atmosphere of the University for that of the works ; and that is that genuine scientific work devoted to the purposes of producing wealth is neither a poor thing as science nor a degradation of science. It is true that one can point to innumerable instances of hopelessly bad and unscientific methods being used in the quest of processes that will pay, hit-and-miss methods which disgrace the training which is credited with having produced them. But that is often not the fault of the industry. It is more often the fault of the training in the Universities, from which a man is sent out either with too limited an armoury, or with too narrow a vision to utilise the knowledge which he has in contending with laws of nature of which he has little or no cognisance.

If you do not hold the view that to produce a good thing cheaply is itself a service to humanity, and that the production of wealth and what wealth means is one of the crying needs of the world to-day, then look on cost of production as simply another variable in your scientific investigations, just as pressure or temperature or concentration are variables, and a very interesting variable it will prove to be.

Unfortunately it does not introduce another degree of freedom. This does not mean that scientific investigation is therefore crabbed or confined, it means simply that one has to take into consideration facts which in the laboratory it has been possible and convenient to ignore. It is not unscientific to attempt to use water, because it is cheap, as a solvent where in the laboratory one would use ether; or iron or wood where one might use porcelain; any more than it is unscientific on the part of a plant to manufacture alizarin or indigo without the use of sulphuric acid or caustic soda. The plant has the harder problem, so has the chemical engineer who essays to produce products by the aid of such materials and methods as the laws of economics allow him.

The production of fine materials cheaply is the ultimate object of the chemical engineer; and every channel by which expense is incurred, whether it be in the cost of materials of energy, of plant, of labour, or of capital tied up in plant and buildings, must be minutely explored.

These several factors, and many others, are so inextricably linked up with one another that it is imperative for the chemical engineer to be in a position to appreciate the influence of each one of them, and to design his plant and method of operation so that the optimum balance is secured. He should therefore be an individual of the widest interests, but have in mind always that the soul of a chemical industry is in the chemical and physical changes of the materials, and it is by the study of the mechanism of these changes that the greatest advances in the design of both plant and process will be made. The two cannot be considered apart.

I have emphasised the economic aspect first because it is from this aspect that the chemical engineer's work will be appraised. He is not, however, going to attain his object by a study of economics, though the economic sense must permeate and control all his work.

The second primary factor with which I wish to deal is concerned with the nature of the problems arising from the increase of scale of operation from that of the laboratory to that of industrial magnitude. The most obvious consequence of such increase of scale is that the laboratory types of apparatus are no longer applicable, and it becomes necessary, for reasons of structural strength and economy, to employ apparatus built of iron, or wood, steel, copper, lead, concrete, brick, or special resistant alloys, in place of glass, porcelain, or rubber. Such apparatus is known as chemical plant. Again, in the laboratory, materials are readily transferred from vessel to vessel by hand; industrially, arrangement must be made for transference by trucks, conveyers, pumps, air blast, suction, or whatever method is most suitable and economical. The various units of the plant must be erected on sound foundations, supported by steel or timber structural work, and housed in suitable buildings.

These obvious consequences of enlarging the scale of operation clearly involve the services of the engineer, and hence in the narrowest sense, but a sense in which the name is often used, we have the chemical engineer.

Ability merely to design plant of suitable capacity, strength, and materials does not, however, constitute a chemical engineer ; neither do the purely structural and mechanical considerations involved in such work constitute more than a fraction of the problems which arise out of the transference of chemical operations to a large scale.

Although the basic process for which a chemical engineer is called upon to design plant may be essentially a chemical process, such, for example, as the nitration of toluene or the hydrogenation of an oil, it is rather the physical aspects of the process which most vitally concern him in his design and arrangement of the plant. The chemical reaction *qua* chemical reaction will have, or should have, been completely worked out before the process comes into his hands, and change of scale, provided it does not introduce new physical conditions, will not alter the direction nor the speed of the reaction, nor the stoichiometric relationships of the materials involved.

The chemical engineer should therefore be in a position to assume that on the purely chemical side all the information he requires will be forthcoming. Nevertheless there are several points even from the chemical point of view that he must investigate. It is possible that by carrying out the reaction in vessels of iron or copper or lead, the reaction itself may be affected, or alternatively the chemical substances involved may attack vessels made from the usual materials of construction. It may be advisable to consider the use of alternative materials in the process itself where advantage would be gained from the chemical engineer's point of view; as, for example, in the substitution of sulphuric acid for hydrochloric acid on account of the greater ease with which it is transported, stored, and pumped; or the use of soda in place of lime on account of the objection to small quantities of dissolved calcium salts in a liquor which has subsequently to be evaporated; or the addition of a flocculating agent to a fine suspension or sludge which might otherwise be difficult to filter. These are a few instances, and the list could be expanded indefinitely of how the chemical engineer can by close co-operation with the chemist mould the chemical operation itself, so that it may be more adaptable to industrial plant operation. He should, therefore, have a broad chemical training; it may prevent much wasted time and expense in the later stages of plant design. It may be said that the chemist is capable of doing all this. He is, and should be, but the fact remains that he frequently is not, and in any case it is the responsibility of the chemical engineer to see that all questions of this nature are investigated before the plant is designed.

The next matter to engage attention is the quantity of the various materials which are to enter or leave the process; where they enter, in what form, and where and how and in what amount they are to be withdrawn. This information, coupled with a knowledge of the time occupied by each stage of the process, is the first essential for the determination of the capacity of every unit of plant required. The latter factor—time—is in a somewhat different category from the former, as it may be considerably affected by change of scale, and it is often economically impossible to duplicate, on an industrial plant, the time flow sheets of a laboratory or small-scale plant. The quantity flow sheet, however, is largely a stoichiometric question, and can be fairly completely worked out on the basis of small-scale experiments. In very many instances it will be found that the chemist has considered the material quantities in detail for only one or two of the materials actually entering into the process, and generally only for one, the specific product desired, of the materials leaving it.

For example, in the preparation of beta naphthol from naphthalene, in addition to naphthalene there would be consumed sulphuric acid, sodium carbonate, caustic soda, hydrochloric acid, and possibly lime. The efficiency of the process would normally be expressed in terms of yield of naphthol obtained per pound or per molecule of naphthalene, but from the point of view of the industrial operation it is also important to know the efficiency on the basis of sulphuric acid, or caustic soda or sodium carbonate; not only from the point of view of cost, but also because of the necessity of knowing accurately how much of each substance must be handled and what quantities of by-products will be available for recovery or what amount of waste material it will be necessary to evacuate.

This material balance sheet or flow sheet must show the mass, volume, and condition of every material, whether valuable or waste, solid, liquid, or gas, moving through the system of plant. Water must be included in the list of process materials, and its entry into the process most carefully controlled, as although easily and cheaply added, it requires valuable plant to contain it, pump it, and heat it, and is expensive to remove either by filtration or evaporation. The economic manufacture of many products depends largely upon the efficient treatment of the water associated with them.

In the preparation of such material flow sheets, the chemical engineer will again co-operate with the chemist. The question itself is mainly a chemical one, but its influence on the design and lay-out of plant is all-important, and the main responsibility in this matter must lie with the chemical engineer.

The chemical engineer must therefore, if his ultimate plant is to be the best that can be evolved, pass in review the chemical aspects of the process which he is to handle. His next step will be to examine the conditions under which the reaction is to be carried out, conditions of time, temperature, speed of reaction, or rate at which physical operations can be conducted. In most cases the temperature is fixed, and the times, of some at least of the main stages of the process, are inherent in the chemical reaction. In many others, and particularly in the case of the more physical processes, such as filtration, drying, evaporation, or distillation, the time factor depends essentially on the design of the plant and may be very considerably influenced by change in the scale of operation.

A very large proportion of the operations carried on in the chemical industries involve energy changes, which generally take the form of evolution or absorption of heat. In the laboratory little or no attention is paid to these changes. If a reaction mixture is to be maintained at a predetermined temperature, or a substance to be dried, or distilled, it is simply placed in a suitable bath, or over a burner ; no attempt is made to ascertain either the quantity of heat which is theoretically necessary for the operation, nor the rate, nor the efficiency at which this heat is supplied. It is such a simple matter to alter the temperature of a small mass of material, in a few moments of time, with the usual facilities of the laboratory. The heat developed, or absorbed, by a chemical reaction involving only grammes of material, or by a physical change such as evaporation, is so small in comparison with the reservoirs of energy under the worker's immediate control that it can readily be overlooked or ignored. The surfaces through which heat has to flow into the material can be made with little trouble as large or small as desired, though the time required for the necessary heat transference is so inconsiderable that the extent of surface is of little real consequence.

On the industrial scale everything is changed.

Energy of whatever kind is expensive to produce and to transmit. It is not possible to maintain unlimited stores upon which to draw, or unlimited reservoirs into which surplus energy can be diverted. It is therefore necessary to know quantitatively what energy is required. Further, the surface of a solid body grows less in proportion to its volume as the linear dimensions of the body are increased. Since the surface of a mass is the channel through which the flow of heat must occur, it follows that, for masses or vessels of similar shape, the supply or removal of heat becomes more and more difficult with increase of dimensions. A heating operation, which in the laboratory may be conducted almost unconsciously in a few minutes, may require hours on a large scale. A heat of reaction which may be dissipated in the laboratory by immersing the containing vessel in a bowl of cold water, or even by the radiation of heat from its walls, may on the large scale be so great in proportion to the area of the boundary surface that unless the most careful consideration is given to the design of the vessel and the supply of an ample reservoir for heat, the reaction may become a wholly unmanageable affair.

It is one of the earliest tasks therefore of the chemical engineer to investigate accurately and quantitatively, not only the temperature conditions which it is desired to maintain in the various sections of his plant, but the input or output of heat units which must be secured in order to maintain those conditions. This investigation involves, according to the nature of the particular operation, a study of the specific heats, latent heats, heats of solution and absorption, heats of reaction, or the energy required in terms of heat units to separate liquid or gaseous mixtures. All these quantities are definite quantities dependent upon the operation or reaction, and a theoretical or experimental value can be assigned to them. That value should be known just as surely as the masses of material to produce a given weight of product should be known. It is impossible to conduct an operation in which heat energy is not wasted, but the chemical engineer should be able to trace those heat losses and to assign an energy efficiency, or thermal efficiency factor, to his process in exactly the same way as he assigns a factor for chemical efficiency.

It is not sufficient that he should know that a certain quantity of coal or gas is being burned at his boilers or in his furnaces; he must know where and how the potential heat units in his initial fuel supply are utilised or lost, and to what extent each separate stage of the whole cycle of operations is thermally efficient. Only by detailed knowledge on these lines can losses of energy be traced and avoided. A simple example of how energy can be lost is that of the distillation of water; theoretically, no energy is needed to distil pure water, and only a comparatively small amount to separate water from a solution. The great bulk of the heat energy supplied in any distillation process remains as latent heat in the vapour and is recoverable; the problem which confronts the chemical engineer is to decide how far the cost of the plant to recover that energy out-balances the value of the energy recovered. That may be a very complex problem, depending upon the price of fuel, the certainty of its supply, the cost of labour, the magnitude of operation, the use which can be made of the recovered energy on the spot (for it cannot be stored), and a number of other factors; which, incidentally, emphasises again the need for a wide outlook on the part of the chemical engineer, and in particular emphasises the necessity of knowing where the energy which is put into a process is consumed.

The weapons which the chemical engineer needs for the attack upon such problems as I have indicated are a sound knowledge of the fundamentals of thermochemistry, physical chemistry, and thermodynamics.

Having determined the flow of heat to or from the various units of the plant, there now remains the actual design of these units, which shall permit the flow to proceed at a rate suitable to the operation in view. The problems with which the chemical engineer is concerned here are mainly physical in nature; the transference of heat by conduction, convection, and radiation, through metals and non-metals, through gases, and liquids of varying viscosities; the effect of the static films of gas or liquid which exist wherever two phases meet, and the effect of velocity of gas or liquid on the tearing down of such films.

These are the fundamental factors which influence the design of any plant in which heating or cooling operations are carried out. This quantitative study of energy relationships in the first place, and of energy transference in the second, is so essential to efficient plant design, that, without it, some extraordinary failures have occurred. May I give you an example within my own experience?

A product was to be sulphonated at a high temperature, and the final reaction mixture so obtained, then nitrated by the addition of nitric acid at a low temperature. In the laboratory and even on a small semi-scale plant everything went well; the hot limpid solution, the product of the sulphonation stage, was cooled to the desired temperature—about 20° C.—and the nitrating acid trickled in, the heat of nitration being taken up by surrounding the vessel with cold water and agitating the contents continuously and vigorously. Good mixing and good cooling contact were secured and a gentle progressive nitration was, in the laboratory, the invariable result. A large-scale plant was then designed on similar lines to operate, so far as I recollect, on some two tons of material. In the first place the agitation was not quite so good comparatively as in the smaller vessel, the cooling surface also in a similar vessel had increased only as the square of the dimensions, while the volume and therefore the heat content of the charge had increased as the cube. This would in any case have resulted in a great loss of time, as nitration could not proceed faster than the heat was dissipated; but there was worse to come; the limpid fluid, when cooled, was in fact a supersaturated solution, and unless nitrated within a comparatively short period, was capable of setting to an almost solid, paste-like mass.

The agitation, as I have said, was not so vigorous as it should have been, with the result that the film in contact with the cold walls of the vessel became super-cooled and pasty long before nitration could even be started, greatly reducing such heat removal as there was. The final result was that nitration had to be conducted in a thick pasty mass, into which the acid could not be properly mixed and the operation required some three to four times the period estimated. The nitration process itself was inefficient, and yielded an impure product, while the whole of the remaining units of a large and complicated plant were working to only 25 to 30 per cent. of their capacity, with the result that the ultimate cost of production was nearly double what it should have been.

This is an example, and a comparatively simple one, of the consequences of not determining quantitatively the heat developed during a reaction, the cooling surface required to dissipate that heat, the time in which a supersaturated solution tended to crystallise, and the effect of inefficient agitation upon the course of the nitration. All this information was essential to the chemical engineer, who was responsible for the erection of the plant, but none of it had been obtained; indeed, in the laboratory the factors mentioned had not been in evidence, since the cooling and agitation of a small amount of material had been more than sufficient to control the temperature of the reaction mixture. One could cite, and any of you who have had experience of large-scale manufactures could cite, innumerable other cases in which expensive industrial plants have been erected, only to find that output has been reduced in similar ways.

It is not just horse-sense that is required to prevent errors of this kind, as is sometimes claimed. Horse-sense will accomplish a good deal; indeed, I would go so far as to say that frequently horse-sense, combined with a little chemical and engineering knowledge, has achieved more than an encyclopædic knowledge of chemical or engineering theory with no ability to apply it.

Another direction in which physical and physical-chemical principles enter largely into the preliminary design of plant is in the mechanism by which substances are transferred from one phase to another and the rate at which such transference takes place.

Such phenomena are the rate at which liquid will diffuse through and evaporate from a wet material or from a free liquid surface, or the rate at which vapours are absorbed from air by liquids or solids having the power to absorb them. A knowledge of these principles is essential to the design of plant for drying material, the recovery of solvents, the scrubbing of coal or coke-oven gas, the washing of gases containing nitrogen or sulphur oxides, and many other purposes. The effect of surface, vapour pressures, equilibrium pressures, velocity of solution or reaction, are the fundamental phenomena upon which design in such cases is based.

Industrial plant design rests to a very great extent upon the velocity with which operations can be conducted, and the effects of increase of surface, speed of agitation, fineness of subdivision, catalytic accelerators, must all be considered by the chemical engineer with a view to reducing the necessary time of operation.

The everyday process of filtration frequently presents untold difficulties, and a study of rates of precipitation and conditions of precipitation may revolutionise the outlay required on filtration plant, as may also the conditions under which the filtration process itself is carried out.

I have by no means exhausted the field which must be explored before the design of plant for carrying out a chemical operation can be satisfactorily performed, but I have said enough to show how inseparably plant design is bound up with the fundamental physical and physical-chemical properties of the materials and reactions involved.

I pass on to what is required of the chemical engineer from the more engineering point of view.

Engineering, in certain of its branches, has been described as "applied physics." If to both sides of the equation we add chemistry, we find that chemical engineering is another term for applied physical chemistry, a definition which I think is due in the first place to Professor Donnan. May I say here how much this new department owes to the interest and stimulus of Professor Donnan and how much we hope to run into debt in the future with that same generous and far-sighted creditor? But for this being, in part, a personal inauguration as well as an inauguration of the department, this address would have been more fittingly and more ably delivered by him.

I have reminded you that, in some respects, engineering may be considered as a form of applied physics. It is of engineering in that sense that the chemical engineer is most in need. If I may so put it, the problems of the chemical engineer are largely physical and physical-chemical in their origins, but the technique by which he must handle those problems is the technique of the engineer. The chemical engineer must be master of that technique in so far as it affects his work. The actual plant he will design and employ is not, from the purely constructional point of view, complex or difficult of design. It does not, as a rule, demand the niceties of construction required in the building of turbines or motors, or the complicated trains of mechanism found in machine tools or textile machinery.

The main part of the chemical engineer's work from the purely engineering standpoint lies in the provision of reaction vessels, correctly proportioned to the operation to be carried out in them, mechanisms for agitating the material within, or transferring material in solid, liquid, or gaseous form from one vessel to another. The chief difficulties arise from the unusual chemical and physical actions which the plant is called upon to withstand, and the limitations which such considerations impose on the free choice of materials of construction.

Apart from the actual vessels of operation, the chemical engineer is concerned mainly on the engineering side with prime movers and generators of energy, with methods for the distribution of heat, mechanical and electrical power, and with various kinds of pumps, lifts, and conveyors for the transference of materials. He must therefore be trained in the principles of design and the underlying scientific principles of operation of the commonly used types of steam boilers, steam, gas, and oil engines, water turbines, electric generators and motors. Above all he must have a thorough training in the methods of utilising fuel of all types and under all conditions. The efficient use of fuel is essential to every industry, and is the foundation of economical working.

I have stressed in this review of the work of the chemical engineer the importance of the physical and physical-chemical outlook, because I feel that it is from this standpoint that the greatest efficiency in the design of plant and the greatest advances in economic chemical operation will be secured. There is also an unbounded field for the "pure" engineer, if he will but learn to look at his problems with a knowledge of some of the fundamental physical principles to which I have referred. It is an undoubted fact that most of the greatest advances that have been made in chemical plant design have been made by engineers who have had no specific training in either chemistry or physical chemistry. One has only to mention the developments that have taken place in the manufacture of crushing and classifying machinery, evaporators, filter-presses and continuous filters, reaction vessels, autoclaves, special pumping machinery, scrubbing towers, extraction and distillation plant, to realise that this is so.

The industrial chemist is becoming more and more dependent upon the leading manufacturers of these standard types, and is rapidly growing into a mere assembling machine, accepting plant often without the faintest idea of the fundamental principles upon which it is designed or the conditions which govern its efficient operation.

It is the manufacturers of these standard plants who, more enlightened than the chemist himself, are realising to a greater and greater extent the need for the knowledge of those fundamental controlling principles which the trained chemist or physicist is specially qualified to give them.

Great advances are being made in this way, but still greater would be made if the engineers themselves were in a position to employ the tools of the physical chemists. We trust that many engineers will see the opening which the chemical industry affords them, and that some at least will come to study with us in the Ramsay Laboratory.

It is well that the industrial chemist should have such makers of repute to whom he can turn for standard plant. It is, however, lamentable that he who uses them and who, above all others, should be in a position to see their failings and show the road to improvement, should in many instances be ignorant of the principles upon which they operate, and unable to design new plant for the peculiar operations or conditions which a new process may impose upon him.

It is not sufficient to say that he can collaborate with an engineer ; if he is not trained to see the problems which await solution, he will probably find nothing about which to collaborate.

It is in the chemical works themselves that trained chemical engineers are needed, for it is there that the problems are awaiting discovery and solution.

The manufacturers cannot be expected to find out one tithe of these problems, when often they are not permitted to enter the works and sometimes even debarred from knowing the material or process with which they are expected to deal.

How can an apparatus whose efficient action may depend upon complex considerations of partial vapour pressures, equilibria constants, latent heats, heats of reaction or velocity of reaction, be designed, when the designer does not know what the substances are with which he is dealing? Yet this is often the predicament in which a plant manufacturer is placed. All he can do is to say, "Well, it looks like so and so. I should think from my experience it will behave like so and so, for which I supplied a plant last year and about which I have received no complaints. Provided it does not contain so and so, and will not do so and so on heating (the onus of which I will place on the chemist who instructs me), I will recommend my standard fool-proof so and so, and allow a 100 per cent. safety factor to cover me against probable inaccuracies in the data supplied to me." The plant is supplied; the user is highly pleased when it does perhaps 10 per cent. more than he asked for; and so it goes on, perhaps for years, until someone comes along who understands both plant and process and does the same work in a plant half the size and at half the cost.

Perhaps I have painted an extreme case, but is it a fantastic one? I think most manufacturers of plant have met it in one guise or another. Indeed they have profited by such cases and used the knowledge gained to improve their plant, and called it—"experience"! Such methods do eventually lead to sound plant design, based on experience, but in many cases the experience is a long and costly one for somebody. It is in the hope of being able to short-circuit some of this "experience" that this department has been formed to train men in the fundamentals of chemical engineering.

We cannot hope to do more than that; our men will still have to gain their experience of the practical application of their principles and will not be chemical engineers until they have done so.

The moral of the above fable—and all fables should have morals—is that any man who designs a process, or who orders a plant to be made, should be a trained chemical engineer, even although he himself may not actually build the plant. This is not detracting from the value of the manufacturer of specialised plant.

In nine cases out of ten, where a standard operation such as evaporation, filtration, drying, or distillation was involved, the chemical engineer, after investigating his particular problem, would be wise to approach the specialist manufacturer, whose particular apparatus was most suited to the problem in view.

He should, however, be able to make his own decision as to what type of apparatus would be the most suitable to the nature and scale of the operation contemplated and what modification would be necessary to enable the apparatus to work with the maximum efficiency.

Where no suitable standard type of apparatus existed he should then be able to determine by experiment the data for the design of the necessary equipment and himself design the proportions, the disposition, and the structural details of the several parts of the apparatus.

I have attempted to give you, in the short time at my disposal, some idea of what we believe to be the scope of the chemical engineer and of the type of man which it is the aim of this department to produce.

I do not pretend to have exhausted the subject of the chemical engineer, either in chemical industry or as a builder of chemical plant, but only on a few selected points to have indicated the *attitude of mind* which the chemical engineer should bring to bear upon his work.

I propose now to give you an outline of the course of training which we intend to give in the Ramsay Laboratory.

We are faced at the outset with great difficulties, arising out of the enormous extent of the field which can reasonably be called relevant to the chemical engineer. It is obviously impossible, except in a course extending over several years, to attempt to deal in detail with every branch of it.

The very real danger of dispersion of effort is shown by the experience of the American Universities and technical institutions. There had grown up in America the most extraordinary variety of courses, depending upon the particular ideas of the teaching staffs and the special industrial needs of the districts in which the institutions were placed.

The position had become so unsatisfactory that in 1918 a committee, under the chairmanship of Mr. Arthur D. Little, was appointed to consider the training of chemical engineers, as then carried out.

The report of that committee was presented a little over a year ago, and is a striking document, particularly in the attention which it calls to the multiplicity of subjects dealt with.

No less than 210 subjects were considered by seventy-three institutions as pertinent to the training of a chemical engineer and were included in the curricula. They ranged from Chemical Philosophy to Political Ethics, and from Civilisation to Irish History. One does not quite see how "Civilisation" should be treated as a subject of instruction, though I am sure it would go well in harness with Irish History; the difficulty would be felt in linking them both up with Chemical Engineering.

The committee in their findings rightly protested against such needless multiplicity, and recommended, as a background for specific instruction in chemical engineering, strong courses in chemistry, physics, mathematics, and engineering. Even this limited subdivision must tax the time of the student to the utmost.

It is clearly impossible within the four or five years, which is the maximum that the great majority of students can give to their University education, to attempt to make a man a fully qualified chemist, physicist, and engineer. By "fully qualified" I mean one who has obtained such grasp of the theory and methods of his subject as to be able to apply them, with initiative and imagination, to the many novel problems which will present themselves in the course of his professional career.

In order to do this, the student should, before he begins to specialise in the specific subjects of chemical engineering, become what I may call a thoroughbred in one branch of the fundamental sciences, either in chemistry and physical chemistry or in engineering. He will, before entering the chemical engineering department, graduate in one of these schools.

It is not intended, during this initial period of three years required for graduation, to give a half-and-half chemistry and engineering training. As the University courses are now planned, it would be quite impossible for a man to become efficient in either branch of his training by such a method.

The course in the department of chemical engineering is therefore, for the time being at least, a post-graduate course, which will occupy one or two years according to the nature of the training and acquirements of the student.

When the course is of two years, the first year will be devoted to lectures, drawing office, problem and laboratory work, designed to supply the additional training required to enable the student to apply his scientific and engineering knowledge to the specific problems of chemical engineering. The second year will be devoted to advanced work and the carrying out of original investigations on chemical engineering problems.

The greatest importance is attached to this second year's work as giving the student experience in the solution of problems in which he will be dependent on his own initiative for his method of attack and on his own hands for the building of the apparatus he will require.

The general scheme of instruction in the department will be arranged under the following main groups of subjects:

Section I. The generation and distribution of energy. This section will deal with the prime sources and the methods of distribution and use of steam, electricity, and power gases. We do not intend to deal in detail with the actual design of either steam boilers, electrical generators or motors, except in so far as this knowledge is required in order to choose such plant intelligently and to operate it efficiently and economically.

This requires a knowledge rather of the underlying principles of power supply, and in particular a detailed knowledge of the theory of combustion of fuels and the preparation of thermal balance sheets.

Section II will deal with the transference of energy to materials; a very important subject, and essential in almost all problems of chemical plant design. It will be treated from the fundamental thermo-physical point of view in the first place, after which will follow detailed investigations of the various types of apparatus used industrially for the transference of heat to materials. Problems will be worked in the design of preheaters, heat regenerators, the heating and cooling surfaces for stills, and other standard types of chemical plant.

Section III will deal with the handling and transportation of materials; the physical laws controlling the flow of liquids and gases through pipe lines; the effects of friction and viscosity of fluids on the power required to pump them; and the calculation of the cost of such transference. It will also include illustrations of the main types of apparatus used for the pumping, lifting, or conveying of materials, and the principles which govern the choice and lay-out of transportation systems.

Section IV is mainly intended for students who have had little or no engineering training, and is designed to give them a knowledge of those branches of mechanical and constructional engineering which are required in the design and erection of plant. I will not go in detail into the actual syllabus, as the needs are well known.

It will also include classes in engineering drawing and the use of engineering tools. The latter is very desirable, as the chemical engineer will frequently, in the course of his investigations of processes on a semi-large scale, be called upon to make the plant he requires with his own hands.

He should be as capable in such operations as fitting, lead burning, soldering, and turning as the physical chemist is in glass-blowing. They are his necessary tools.

In this connection it would be an invaluable thing if every man who is considering entering the profession of chemical engineering could, either before or during his college training, work for some time in a humble capacity at some engineering works or in the repair shop of a chemical factory. He would obtain experience of great value to himself, and an insight into the conditions of labour and a sympathy with labour which would remain of the utmost value to him in after life.

Section V deals with the preliminary preparation of materials for use in chemical operations, and treats of the physical principles of operation and of the common types of plant employed for such operations as the crushing, grinding, mixing, and classifying of solids.

Section VI is devoted to familiarising the student with the chief measurements and instruments used in the control of works plant and processes, other than methods of analytical chemical control. Such measurements, for example, as the determination of calorific values of solid, liquid, and gaseous fuels ; the viscosity and flash-point of oils ; thermo-electric, optical, and radiation pyrometry ; the various types of flow meters and recorders for liquids and gases.

Section VII, which is one of the most considerable in extent and most important in content, deals with the design and operation of specific unit types of chemical plant and process. It is our intention to deal not with particular technical processes so much as with the fundamental physical and physical-chemical principles underlying each specific operation. The operations may be classified generally as physical or chemical, and are met with in one form or another in almost all chemical industries. The former consist mainly of processes of separation, whether of solids from solids, solids from liquids, liquids from gases, or of mixed liquids and mixed gases.

I will not attempt here to enumerate all the different methods and plant available for such separations, but it will readily be seen that they must depend fundamentally upon physical and physical-chemical considerations. Phase law and thermo-dynamic principles govern the processes of distillation and fractionation. The equilibria between vapour and solution, and the rate at which vapour is transferred from one phase to another, control rates of drying, evaporation, and gas absorption in washing towers ; the laws of surface absorption and flow of liquids through capillaries govern the processes of filtration of solids from gases and from liquids.

Phase law and solubility considerations govern the efficiency of lixiviation or crystallisation processes, while considerations of latent heats of evaporation, specific heats, heats of solution or absorption, rise or fall of boiling point with change of pressure, enter vitally into the design of plant for all processes in which changes of phase take place.

For the second group of chemical type operations, design of plant is to an equal degree governed by an accurate investigation of heats of reaction, chemical equilibria, velocity of reaction, effect of the state of division of the reacting materials, and of speed of agitation or intimacy of contact.

We propose to deal with the manner in which these various factors affect and control the arrangement of plant required; for example, its volume, in order to give sufficient time of reaction, or time for a physical process to go to completion; its heating or cooling surfaces, in order to permit of the necessary heat absorption or evolution; its arrangement of piping or channels in order to give free passage to the flow of vapours or liquids. The student will be taught to obtain the data required in any individual case, either by experiment or from the literature, and will himself design and prepare, in certain cases, working drawings of the plant required.

We realise to the full that, though these fundamental considerations are capable of yielding very valuable information upon the problems of plant design, yet the processes with which we have to deal are often so complex, or are affected by factors so inconstant, or so difficult of isolated investigation, that it is impossible to design plant from laboratory data or from theoretical considerations alone.

The science of chemical engineering has not yet reached that state of precision in many instances; for example, that of filtration probably never will. Even in such cases, however, a sound appreciation of some part of the underlying theory of operation is of the greatest assistance in the correlation of facts observed in the laboratory and on the industrial plant, and so leads to more efficient and more certain design of succeeding installations.

In order to take us one step nearer to industrial conditions, we have included in our building a large laboratory for the erection of plant of a semi-scale nature. We do not intend this to be a museum for the display of working models of industrial plant, but rather a flexible workshop, provided with all necessary services of water, vacuum, compressed air, steam, gas, and power, in which as occasion demands we can build up any unit or sequence of units for the demonstration or investigation of particular problems, in apparatus of the same type as would be used on the large scale.

As far as possible, and where it can be accomplished without needless waste of time, the building and assembly of such plant will be performed by students to meet the requirements of their particular investigations. We have also available close at hand a desolate open area which we propose shortly to provide with a temporary cover, a complete equipment of services—and a fire policy. Into this shelter it is intended to turn anyone with really elevating ideas and initiative.

The next section (VIII) of our programme is also a particularly important one, but will not take long to describe here as it is in the nature of a gathering up of matters which I have already discussed at some length. I have called it the "Correlation of Chemical Process and Unit Type Operation to form the complete Industrial Process." It is intended to give practice in the methods by which the chemical engineer should proceed in the drawing up of a scheme for the lay-out of plant for a complete industrial undertaking.

Starting from his review of the chemical aspects of the process, which would include an investigation of the materials of construction available, he would prepare detailed material and energy flow sheets, based on laboratory, semi-scale, and (if the process had been already operated on a large scale) on large-scale investigations. He would couple with these the time sheets, showing, as far as possible from available information, the time occupied by the several stages of operation. From the combined quantity, energy, and time flow sheets he would then determine the capacities and number of the units of plant required for each stage of operation. The design of these working units would be based upon calculations on which the whole of the available data obtainable from laboratory investigation or from observations made upon similar large-scale plant elsewhere would be made to bear. This design work is the essential work of the chemical engineer, but, as we have already seen, success rests upon a thorough appreciation and investigation of the many factors which lie outside the immediate field of design in the usual sense. The lay-out of the plant as a whole with respect to supplies of materials, facility of working, distribution of mechanical power, choice of handling, and transporting systems would then be considered.

This, very briefly, is the type of scheme which the student would be expected to handle after his training in the Ramsay Laboratory. He would, on the basis of his own investigation of some simple process, prepare a general lay-out drawing of the plant required, and a detailed drawing of any individual unit. He will further receive instruction in the choice of the materials of construction and in the preparation of specifications for the work.

Finally, there will be included in the course of studies lectures designed to give insight into certain branches of general industrial economics. This is such an extensive subject that it would be a dissipation of time and energy to attempt to go into it fully. The need, however, is undoubted. We want our men to have that width of interest and sympathy and recognition of the industrial problems which they handle as part of a much greater whole, which will enable them to take that position in the direction of affairs to which technical knowledge alone is not sufficient to entitle them. We cannot do more in this way than indicate in what direction the student should more immediately interest himself when he enters upon an industrial career. I believe this object can best be achieved by inviting men of experience and authority in their several spheres to give special lectures upon such subjects as follows (I have classified them under the broad heading of Industrial Economics):

(1) Location of works with respect to supplies, markets, transport, water, power, sewage-disposal facilities, etc.
(2) Works costing systems.
(3) Methods of financing an industrial concern.
(4) Labour regulations and wages.
(5) Factory administration.
(6) Welfare, and safety organisation.
(7) Effect of magnitude of operation upon cost of production.
(8) Economic chemical geography.
(9) Principles of Patent Law.

There is no time to-night to discuss these subjects further, but I think their importance and application to our purpose are evident. It is hoped that such lectures as I have outlined will draw the attention of our students to, and stimulate their interest in, matters which, though perhaps outside their narrow technical field, are of the most vital importance in the industrial life which they propose to enter.

I have given at length one view of the field of the chemical engineer, and the lines upon which it is intended to work in the Ramsay Laboratory. The programme of work is a heavy one, and to carry it out efficiently and in its entirety will need expansion of accommodation and staff, otherwise freedom for original research, which must be one of the main objects of the department, will be seriously curtailed. At the outset it will be necessary to select those branches of work which lead most directly to the object we have in view. It is also necessary to consider whether the chemical engineering course should remain a wholly post-graduate one, or whether we can receive men specifically for training as chemical engineers at the commencement of their university education. This is a difficult question. The chemical engineer, if he is to perform his most efficient work, must be a trained scientific worker, and not simply a technician in the narrow sense of the word.

Under the present University regulations and organisation of courses, it would undoubtedly be unsatisfactory to attempt to formulate a joint chemistry physics and engineering course. Such a combination would be a patchwork compromise leading only to a training in the elements, and not to that thorough grasp of the fundamentals of the various sciences which the chemical engineer requires.

The subjects of chemistry, physics, and engineering are themselves so extensive that even in the schools devoted wholly to their teaching a selection has to be made. Different selections are in fact made in different schools and all may lead to the desired goal. It is possible that a selection, specially adapted to the needs of the chemical engineer, may be made without impairing that thorough grasp of the fundamental sciences to which I have referred, and which at the same time will allow more time to be devoted to the other subjects of primary importance.

A special course of this nature, designed to cover the preliminary three years' training of the chemical engineer, will require increase of staff and a modification of the existing regulations governing examinations and the conferring of degrees, but it may not be impossible of attainment. The whole question is receiving very careful attention.

In conclusion I wish to point out some of the chinks in our harness, and to call the attention of those leaders of industry who have shown interest in our plans to the way in which they can help us to make them good.

The chemical engineer must be above all a practical man; academic skill and a knowledge of the theory of plant design and operation are of very little use unless accompanied by the knowledge of where theories break down and principles are incompletely known.

A University is a natural breeding ground of theories and principles; it is right that it should be so, for theories are the wheels upon which masses of unrelated observations may be brought easily and rapidly into an ordered system. A thorough training in the fundamentals upon which industrial chemical operations are based is the soundest foundation upon which the chemical engineer can build; but that in itself is not enough. We must not allow a barrier to be drawn between fundamentals and their application. The student *must* go out into the works while he is still passing through his training. He must have opportunity of gaining experience of large industrial operations, and the actual working of plant, of the outlook and methods of labour, of the ordinary routine of factory life, and of the practical application of the principles of chemical engineering. Work in our own semi-scale laboratory does not provide what is needed, that is mainly for investigational purposes. We hope to arrange, with the co-operation of the industries, for our men to spend at least six months during their University course in a chemical factory. We shall look upon the time so spent as being an indispensable complement to their work at the University, and intend it to be, if at all possible, an integral and compulsory part of our course. In planning such a course of industrial practice, we have two main objects in view. First the general education of the student along the lines I have indicated, and second the methodical scientific investigation of chemical engineering problems on a scale which it is impossible to provide outside a factory. We should not expect, and do not need, to be admitted to factories or parts of factories where the operations are the trade secrets of the industry concerned.

Our men can obtain splendid experience, and can investigate problems in design, and efficiency of operation, on plant and processes which are not secret in any way. Such problems, for example, as the mechanism and efficiency of absorption in towers, the thermal balance sheet of an oil distillation unit, the electro-chemical efficiency of an electrolytic process, or the material flow sheet of a sulphuric or nitric acid plant. These problems could be investigated without in any way interfering with the plant or with the regular operation of the process, and might well lead to information of quite unexpected value to the owners of the plant.

On the other hand there are problems of a more fundamental nature which arise in every industry, problems which require preliminary laboratory and small-scale investigation, the time and facilities for which the industry may not be able to provide. Frequently such problems are of fundamental scientific interest and may well be transferred to a University laboratory. We shall be glad to receive suggestions of such problems as are of interest to the chemical engineer, and hope when we have developed further, and have men who are ready to undertake original work of that nature, to devote a section of our laboratory to meeting the immediate needs of industry.

We are dealing with a living subject, and by such co-operation as I have suggested we hope to keep it a living subject within our laboratories. The industries can help us, and in helping us will secure more certainly the objects which we in this work all have at heart : the provision of trained, thinking, imaginative men to play their part—and we believe it will be a worthy part—in the development of chemical engineering in its broadest sense, and through chemical engineering the well-being and prosperity of our chemical industries.

APPENDIX

SYLLABUS OF PROPOSED COURSES IN DEPARTMENT OF CHEMICAL ENGINEERING, UNIVERSITY COLLEGE

I. Production and Distribution of Energy in Chemical Works

Steam.

General principles of steam generation and distribution.

Scientific control of boiler installations and determination of efficiency.

Fuel and flue-gas analysis and calorific value.

Types of steam-operated plant, steam traps, and meters.

Electricity.

Methods of generation and types of generator. Principles of transmission, voltage, care of cables, transformers, choice of type of motor for special purposes.

Lighting systems, switchboards, and fuses.

Power Gas.

Types of generator, control of producer and water gas plants. Calorific value and analysis of gas. Distribution. Types of gas and oil engines.

Choice of Power.

Advantages and limitations of various types of power under conditions of chemical industry.

It is not intended to deal with the actual design of either steam boilers, electrical generators and motors, or gas and oil engines except in so far as to ensure efficient running and maintenance.

II. Transference of Energy to Materials

Theory of heat transfer by radiation, conduction, and connection between solids, liquids, and gases. Effect of nature of materials and boundary films of liquid and gas. Main types of apparatus for supplying heat—coal, gas, and electric furnaces, heating by condensing steam, superheated steam, and hot oil circulated.

Head conservation, heat exchangers, air preheaters and coolers, prevention of radiation losses from pipes and reaction vessels. Radiation losses from furnace walls.

Cooling systems—jacketed vessels, internal pipes, direct cooling of gases by water spray.

Design of plant for these several purposes based on fundamental laws of heat transfer and comparison of actual duty obtained with that calculated.

Determination of economic balance between heat conservation and capital expenditure on plant.

III. THE HANDLING AND TRANSPORTATION OF MATERIALS IN CHEMICAL WORKS

Laws governing the movement of liquids and gases through pipes and method of measuring fluid flow.

Calculation of power requirements and cost of transference.

Lay-out of pipe lines for gases and liquids.

Principal types of apparatus for transference of materials.

(a) *Solids.*—Cranes; bucket, belt, screw, compressed air, and suction conveyors.

(b) *Liquids.*—Pumps, pulsometers, air lifts, montejus, ejectors.

(c) *Gases.*—Fans, pumps, compressors, ejectors, chimney draught.

Influence of nature of material on choice of apparatus.

IV. MECHANICAL AND STRUCTURAL ENGINEERING

(a) *Materials of Construction.*

Metals, non metals, resistance to chemical action and physical changes. Mechanical strength.

Choice of materials for specific purposes.

(b) *Principles of Construction.*

Foundations, steel, wood, and concrete structures.

Working stresses and factors of safety. Wind pressure on towers and chimneys.

Design of simple schemes and specifications.

(c) *Applications of Theory of Machines.*

Principles of simple machines. Toothed, bevelled and worm wheels, friction gears and clutches, lay-out of shafting, fast and loose pulleys, chain drives, hydraulic presses, lifts, etc.

(d) *General.*

Lay-out of pipe lines, pipe fitting, methods of jointing pipes in different materials, principal types of steam, water, and gas valves. Erecting and dismantling standard types of pumps, compressor and vacuum, gas and oil engines.

V. THE PREPARATION OF MATERIALS FOR USE IN CHEMICAL PROCESSES

Principles of the design and operation of plant for the carrying out of such operations as crushing, grinding, mixing, and classifying. The influence of size of particle upon the speed and efficiency of chemical reactions.

VI. FUNDAMENTAL CONTROL OPERATIONS FOR CHEMICAL PLANT AND PROCESSES

Mainly practical work to familiarise the student with some of the chief measurements and instruments ordinarily employed for the control of works processes, other than analytical chemical control.

Calorific value and analysis of coal, fuel oil, and gas.

Viscosity and flash-point of oils.

Recording gas and mercury thermometers, thermo-electric, optical, and radiation pyrometry.

Pressure gauges and recorders, CO_2 recorders, etc.

VII. THE DESIGN AND OPERATION OF UNIT TYPES OF CHEMICAL PLANT

The underlying physical and physico-chemical principles governing the design and operation of plant for the carrying out of processes under the following headings.

The data for any particular operation are obtained either from the literature or experimentally in the laboratory and the work is correlated with that of the drawing office where the design of a few typical examples is worked out.

(a) *Physical Type Operations* (mainly separations).
  (i) Separation of solids from solids.
    Extraction, lixiviation, and leaching.
  (ii) Separation of solids from liquids.
    Crystallisation, filtration, centrifuging, settling.
  (iii) Vaporisation processes.
    Drying, evaporating, and distillation.

- (iv) Separation of mixed liquids.
  - Fractional distillation and condensation.
- (v) Separation of gases or vapours.
  - Absorption in oil or other solvents, use of solid adsorbents. Compression, refrigeration.
- (vi) Separation of solids from gases.
  - Filtration, centrifugal separation (cyclones), electrostatic precipitation.

(b) *Chemical Type Operations* (methods of reaction).

- (i) Production of gases.
  - Gaseous fuels, sulphur dioxide.
  - Fractionation of liquefied gases.
- (ii) Reactions with gases.
  - Oxidising, calcining, contact gas reactions, hydrogenation, SO_3 manufacture, ammonia and nitric acid synthesis.
- (iii) Reactions in liquid medium.
  - Nitration, sulphonation, reactions under pressure in autoclaves.
- (iv) Electro-chemical reactions.

VIII. The Correlation of Chemical Process and Unit Type Operation to form the Complete Industrial Process

(1) Preparation of theoretical and practical flow sheets for materials and energy.

(2) Choice of materials of construction for plant and buildings.

(3) Semi-scale trials.

(4) Time flow sheets.

(5) Choice of most economical handling and transporting systems.

(6) Lay-out of plant with respect to supplies of raw materials, power, and delivery of finished product.

(7) Estimating final cost of production.

(8) Control of process in operation.

The student would be expected to draw up a scheme for the manufacture of a product, showing generally the lay-out of plant and buildings required and particularly the flow of materials, power, and energy required for the process. He would also indicate the data to be obtained and the use to be made of the data in testing and controlling the operation of the plant. The basis of this work would be his own investigation of the process in the laboratory and on the small-scale plant, or at a works.

IX. INDUSTRIAL ECONOMICS

(1) Location of works with respect to supplies, markets, transport, water, power, and sewage-disposal facilities.
(2) Elementary knowledge of methods of financing an industrial concern.
(3) Works costing.
(4) Labour regulations and wages.
(5) Commercial side of factory administration.
(6) Welfare work, safety, and first-aid organisation.
(7) Effect of magnitude of operation on cost of production.
(8) Economic chemical geography.
(9) Principles of Patent Law.

The object of this section is mainly to arouse the interest of the student in the subjects named, so that he will not be out of touch with his colleagues on the business side of the factory. This object will, it is hoped, be met by a series of lectures by men of experience and standing in the industry, given at the University.

X. SPECIAL TOPICS IN INDUSTRIAL CHEMISTRY

A general review of the typical processes and methods of operation employed in the leading chemical industries regarded from the chemical engineering standpoint.
(1) Heavy chemical and acid industries.
(2) Coal-tar products.
(3) Organic chemical industries.
(4) Glass, ceramics, and refractories.
(5) Metallurgical industries.

XI. SELECTED PHYSICAL CHEMICAL TOPICS

The applications in industry of certain specific physical-chemical themes, e.g. catalysis, colloid chemistry, phase laws, etc.

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