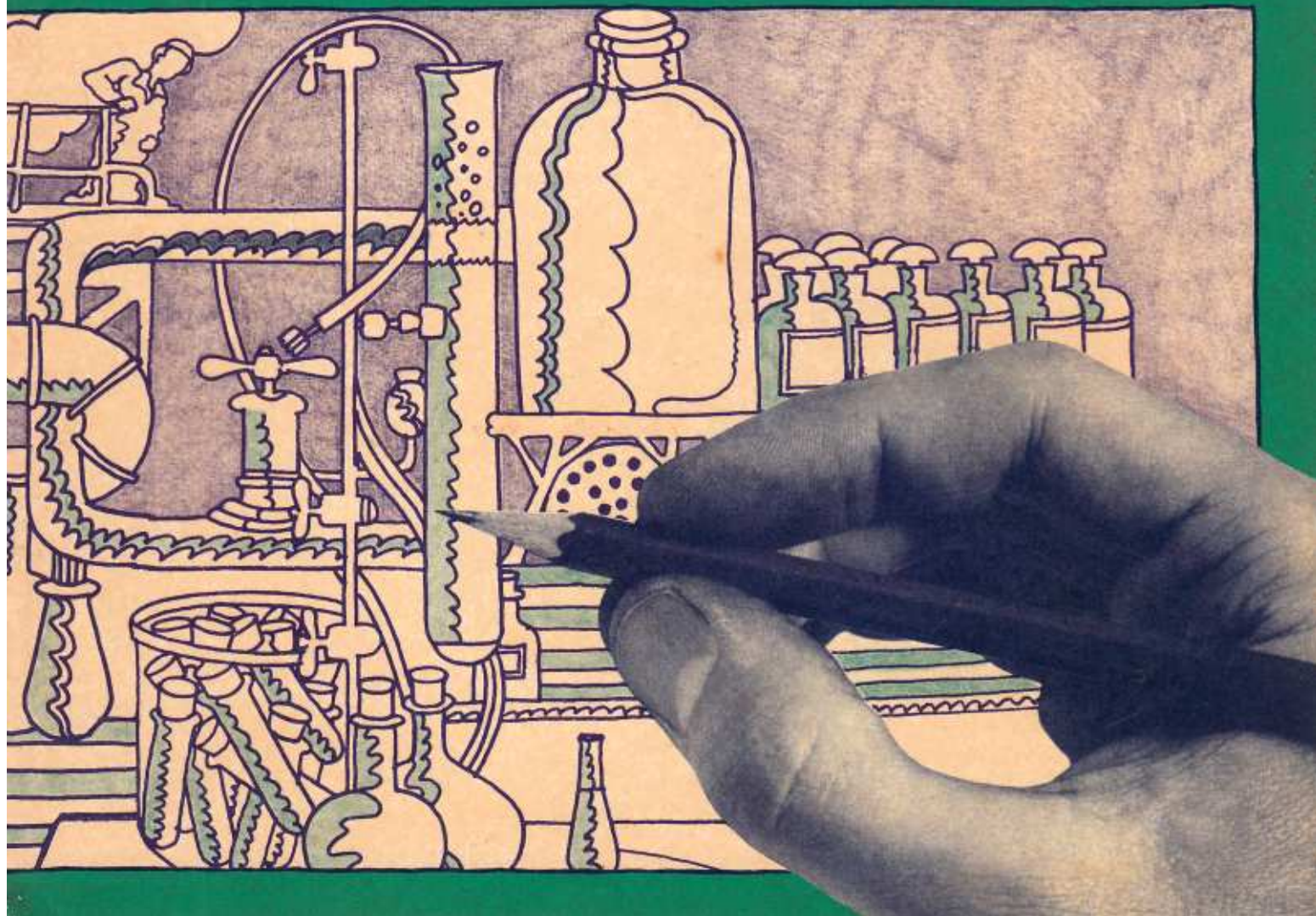


Chemistry Background Book



Chemical Engineering



Chemical Engineering

The chemical engineer has one of the most varied jobs in industry: he must know enough chemistry to understand the experiments that the research worker is doing in his retorts and test-tubes, and be able to suggest possible uses for the chemicals that are made. He must also be an engineer, so that he can design, build, and operate the industrial plant which will make these chemicals. The chemical engineer has to be a jack-of-all-trades, and a master of them as well. As a theoretician who has to show practical results from his labours, he is research worker one day, and the next day plant manager, needing all his intuition and cunning to run his plant. He has been described, probably by some disgruntled chemist defeated in argument, as a man who talks engineering to chemists, chemistry to engineers, and football to other chemical engineers.

Because of his wide range of interests, the chemical engineer must necessarily have a wide range of study. First, he must have a thorough knowledge of the 'three R's' of the physical sciences – physics, chemistry, and mathematics. Without this and without the mental training that goes with it, he will find it impossible to grasp the complexities of such things as thermodynamics, fluid mechanics, and heat and mass transfer, all of which he must understand to carry out his job. As a chemist, his main job is to transform raw materials into finished products, but he must also be able to work out the cheapest, quickest, and most efficient way of bringing about a particular chemical transformation, how many reactions will be involved, the kind of equipment needed, and the yield of products to be expected. He must also know how to separate the finished products from the waste materials, using such techniques as fractional distillation, solvent extraction, crystallization, and filtration.

As an engineer, he must know how to construct distillation columns that can withstand the pressures and temperatures at which they operate, and that are not eaten away by corrosive liquids. He must know how to build foundations for the process vessels so that these will not blow over in a gale or sink into the ground. He must know how to arrange for a supply of electricity to the electric motors that will be used when the plant is running. In short he selects and studies those parts of the other engineering disciplines that will be useful for his job of designing, building, and running a chemical process plant.

But perhaps the most important thing a chemical engineer has to learn is the ability to think clearly in confused situations. He will not usually acquire this knowledge during his formal training, but in later life, when the outcome of his calculations is an order to a manufacturer for a distillation column, not marks in an examination. In order to demonstrate some of the situations in which a chemical engineer may find himself, and what he does about them, the rest of this book consists of the life history of an organic solvent now being manufactured by one of the major chemical companies in the U.K. The solvent will be called RD 100, its original name, for reasons of secrecy.

RD 100 was discovered several years ago in the laboratories of a large company which manufactures a wide range of chemicals. The directors are practical men – many of them have M.I.Chem.E. (Member of the Institution of Chemical Engineers) printed on their business cards – and they understand the value of research. The firm has a large research division and does most of its own process development work although chemical engineering contracting companies are often consulted for major projects.

Most large chemical firms have research laboratories, and it is here that commercially useful substances are often discovered.
C / B A. Laboratories Ltd.



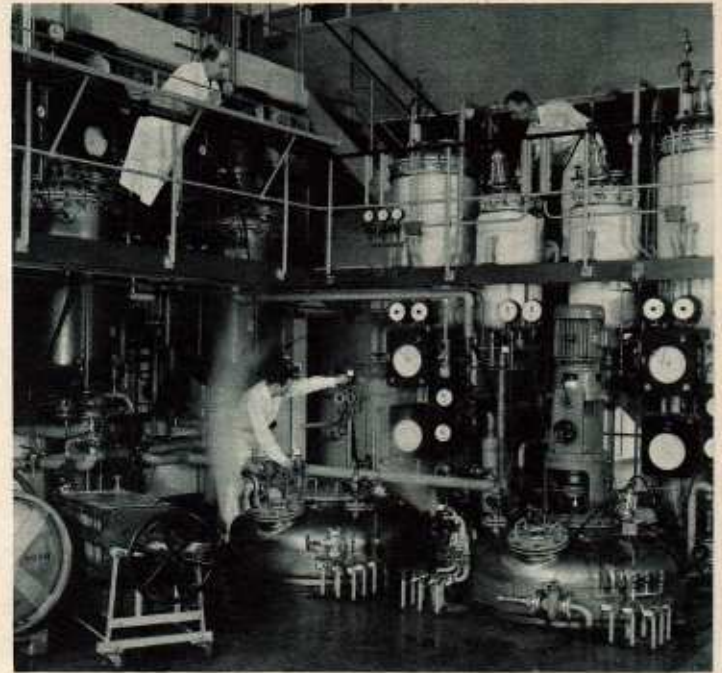


Standard equipment in most industrial chemical laboratories is gas chromatography apparatus for making quick and accurate analyses of substances. *British Hydrocarbon Chemicals.*

A young chemist was engaged on a search for a new catalyst for one of the company's well-established processes. He was trying various catalysts and using a gas liquid chromatograph (GLC) to analyse the products of his experimental reactor. When a mixture of chemicals is put into a GLC, a stylus draws a series of peaks on a moving sheet of graph paper, each peak corresponding to a particular compound. One day the chemist noticed a peak which he had not seen before. From the shape and size of the peak, he concluded that his sample must consist almost entirely of one chemical. He thought the chemical might be interesting and, having kept an accurate record of his experiment, he was able to prepare, this time deliberately, a few pounds of what he called RD 100. He passed a sample on to one of his colleagues who weighed it, heated, pulled and pushed it, dissolved things in it, and became more impressed by its performance after every test. Together they wrote a report, hailing RD 100 as an extremely versatile solvent, and left the bulky file on the research director's desk before returning in a cautiously optimistic mood to the laboratory.

The research director was a hard-bitten man and had seen many wonder chemicals turn into dusty samples on the laboratory shelf, but he was sufficiently impressed by RD100 to call in the manager of the pilot plant, the first of many chemical engineers to have dealings with the solvent before it came on the market.

A pilot plant manager controls a strange empire that is something between a laboratory and a modern chemical plant with its huge array of pipes and distillation columns. His job is to bridge the gap between the laboratory and the full-scale plant so that costly mistakes can be avoided when it comes to manufacture. At this stage the word 'cost' begins



to feature increasingly in the history of RD 100, so more ought to be said about it.

There are many ways of measuring the efficiency of a chemical process and, incidentally, the efficiency of the man who designed it. The amount of product made per ton of raw materials, the amount of fuel oil, electricity, and steam needed to operate the process, the amount of catalyst used – all these are indicators of efficiency. They can be converted quite simply into pounds, shillings, and pence, and an overall cost of the process can be worked out, enabling a comparison to be made between alternative processes.

It is not difficult to design and operate a plant if money presents no problem: stainless steel can be used lavishly, because even tapwater will eventually corrode mild steel. If quick calculations on the back of an envelope indicate the need for a distillation column 40 feet high, then why not build it 80 feet high to be on the safe side? A plant designed in this spirit will no doubt work, but it is bound to be very difficult selling the product at twice the cost of a competitor's material. And in the last resort, of course, that is what matters.

Once the manufacture of a new chemical has been agreed, the first step is to construct a pilot plant – to bridge the gap between laboratory synthesis and full-scale manufacture so that costly mistakes can be avoided.

C.I.B.A. Laboratories Ltd.



Problems encountered in the operation of a pilot plant are often solved in specialist laboratories – as in the distillation laboratory shown here.

C.I.B.A. Laboratories Ltd.

When the manager of the pilot plant was handed over the report on RD 100, he muttered something about having too much on his plate already and went away to plan a series of test runs. The questions he had to answer were these. Could RD 100 be made in large steel vessels as distinct from the glassware which had been used in the laboratory? Which raw materials were needed and what impurities could not be tolerated in them? Could these materials be supplied from the company's resources or must they be purchased outside? He then had to choose a manufacturing process (often quite different in detail from the reactions used in the laboratory) which would give a product of the desired purity and by-products that could be used in other of the firm's processes, sold outside, or, as a last resort, kept to the absolute minimum.

Finally he put away his slide rule and his textbooks and started to assemble his equipment, only to find that he had no filter which would remove the unreacted catalyst from the main process stream. He then remembered an article about filtration he had read recently, published by a friend of his from university days. A meeting was arranged and the university man, who knew a great deal about the flow of liquids through porous solids, was able to make a number of suggestions bearing on the filtration problem. Soon afterwards a complicated contraption appeared in the pilot plant, studded with pressure gauges and taps.

The first test run was a fiasco. In spite of pumps, blasts of air, and even judicious blows with a hammer, lines blocked up. The main distillation column filled up with froth and the reactor got so hot that the building had to be evacuated until the works fire brigade had cooled everything down. There had been yet another demonstration of one of the cardinal principles of chemical engineering: in any process design one

factor is always forgotten. The pilot plant manager returned to his office, muttering angrily, and looked at his calculations again. Pipes! This problem was easily solved – bigger ones were put in. Overheated reactor! More efficient cooling coils were installed and a closer check was kept on the catalyst consumption. The froth-filled column made necessary a visit to the chemical engineering research department where a group of people had been engaged for some years on fundamental research into distillation.

In the distillation laboratory large contraptions of slotted steel girders supported fat glass tubes full of metal thimbles, and red rubber tubes led to and from curly glass condensers. Down at ground level there were electrically heated glass jars full of bubbling liquids of many colours.

When the pilot plant manager came in, the team leader of the distillation section was working at the computer. Many of the calculations in distillation work are mathematically simple, but have to be repeated time and time again, with small corrections each time, until they fit the measured results. A computer can be fed with a mixture of components and their boiling points (on paper tape of course!), and it will distil away happily until all the equations fit. Then it can print out the result on the teleprinter.


Because distillation columns are full of gases and liquids, they are often troubled by frothing. The leader of the distillation team was able to suggest a number of solutions. Eventually they decided on a new type of packing for the column, and the pilot plant manager went off to the workshops with a sample in his hand to be copied. This time the test in the pilot plant went off perfectly.

Several weeks later another bulky report was written and reached the general manager's desk. This report was really the recipe for the new product, giving the ingredients and the method of preparation together with many other details. Meanwhile the commercial part of the firm, supplied with up-to-the-minute information about RD 100, had been busy. The market research department had found out that, provided the price was right and the properties were what they were claimed to be, RD 100 could make large inroads into a market for solvents which had been dominated for years by one of the firm's rivals. It might also find a use in one of the new finishes being developed for motor cars, provided that tonnage quantities were available soon enough. The economics department had worked out a provisional manufacturing cost for the product, taking into account the cost of the plant, the wages of the men who would have to run it, and the cost of feedstocks, fuel, etc., needed to make RD 100.

Now the general manager had to prove to his colleagues (and to the shareholders) that he was worth the large salary paid to him. The decision he had to take was a difficult one: to make the process economical, at least 10,000 tons of RD 100 had to be produced a year, but market requirements for several years ahead did not exceed 5,000 tons per year. But the general manager was a forceful man, and to him the answer was simple: build the plant to make 10,000 tons a year, and send a strongly worded memorandum to the sales director.

As the company did not have the facilities to build a plant of this size, it was decided to call in one of the chemical engineering contracting companies. Such companies do not make chemicals, but develop chemical processes and then design and build chemical plants based on them for the operating companies. In this case it was agreed that the contractors would have access to all the pilot-plant data which had been obtained so far and would take over from there, scaling up the process and then designing, building, and commissioning the full-scale plant.

There are a host of problems, and opportunities, for chemical engineers in this kind of work. Not the least is a problem already mentioned - scaling up. Just as things happen differently in laboratory and pilot plant, so they differ from pilot plant to full-scale plant. New and ingenious mathematical formulae are daily being developed to make it pos-



In building a manufacturing plant, much of the early work is done with pencil and paper.
British Hydrocarbon Chemicals.

sible to predict accurately the amount of, say, heat exchange on a process plant. There is still plenty of scope, however, for past experience in this work, which probably explains the common habit of adding a little bit extra for good measure. But it is a sobering thought that only four people have to add 20 per cent for good measure to a design figure for the final figure to be more than twice the first.

Having solved the problems of scaling, there is still a great deal to be done before the design is finished. The plant has to be operated by human beings, so all the valves that they will turn must be within reach. Some pumps are very hard worked and if they fail the whole plant has to be shut down. But shutting down is a complicated and expensive process, especially when it is done in a hurry, so spare pumps are provided which can be brought into operation immediately one of the main pumps stops. Heat exchangers get dirty, and therefore there must be space around them for cleaning to be done. Even fully automated plants sometimes get upset, and the control system must be designed so that it will make the necessary corrections swiftly and accurately. For the occasions when this is not enough there must be tanks in which

to put the chemicals produced by the plant while the operators sort out the trouble.

While the problems of design for the full-scale RD 100 plant were being worked out by the contractors, the general manager was harrying the company's own design team, which was responsible for fitting the new plant into the existing works, and arranging for it to have all the steam, cooling water, electricity and drains that it needed. He wanted to know why the plant, which he had approved several months before, had not even been built, let alone produced anything. (He knew the reason perfectly well, having had to do a similar job himself some years before, but he also remembered how he had been chased then.) But in the end the finished design was prepared, the price agreed, and the contractors moved onto the site.

The construction team was composed of engineers of all types, and all had their various parts to play in translating a large number of blueprints and drawings into a working chemical plant. In the construction of every chemical plant, there always seems to be time for someone to have fresh ideas. Very often these ideas have already been rejected as



Days of discussion precede the expensive business of building plant to manufacture a new chemical. The need for the new chemical must be established, the quantity in which it will be required, and the best way of manufacturing it.

worthless, and equally often they cannot be made use of because they would delay the whole project. However, the construction team were always prepared to listen and to incorporate what small modifications they could, particularly those of the chemical engineer who was to be manager of the new plant, and who was determined that as many of his ideas as possible should be used.

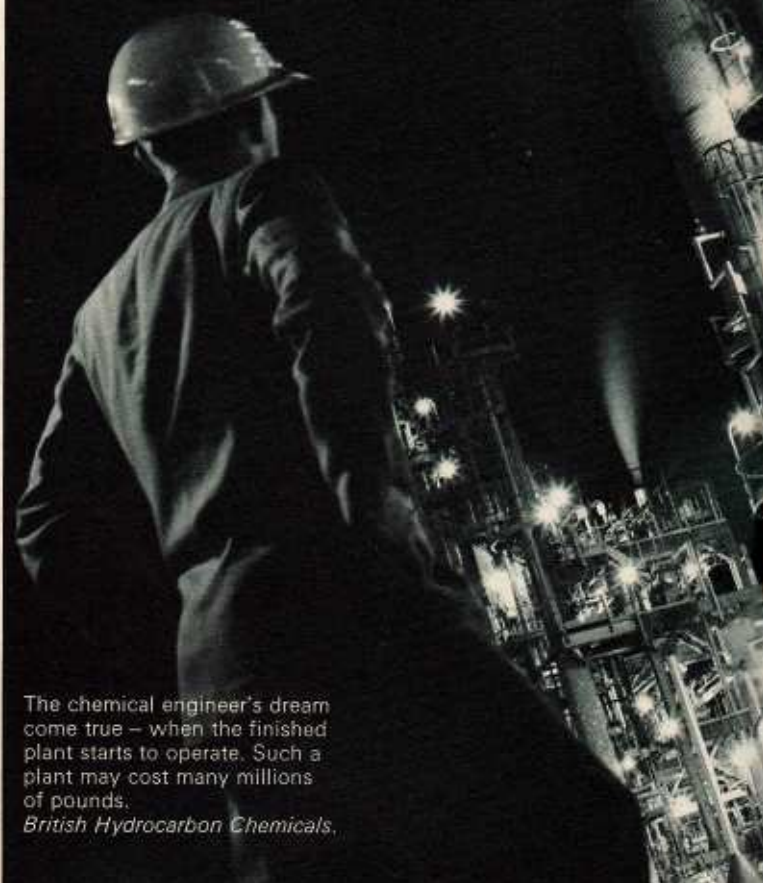
Finally the last bolt was tightened, the last drawing put away, and that most anxious of moments had arrived – the start of a new plant. The plant manager and his process



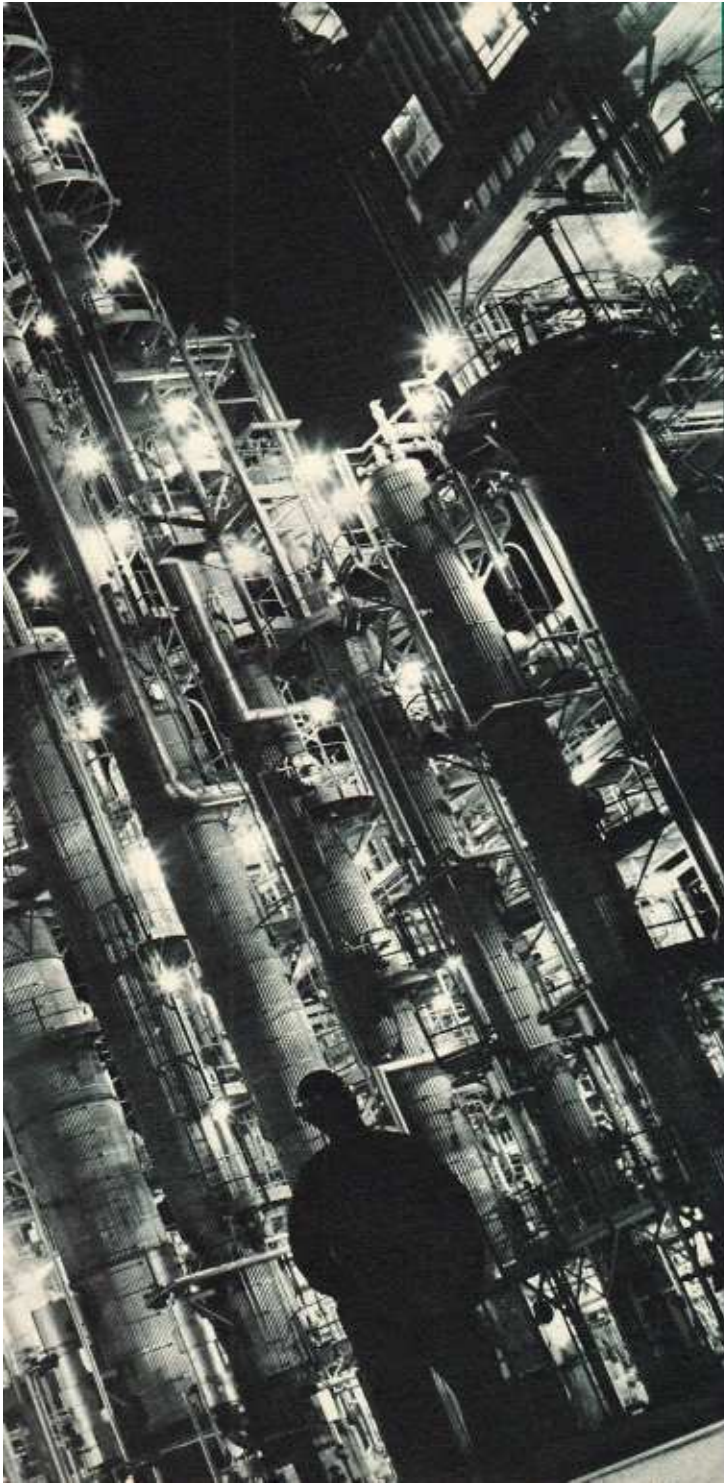
operators worked methodically through each section, making sure that the right pipes were joined onto the right vessels (sometimes they aren't), that the pumps had not been connected back to front, and that the vessels and columns would stand the pressures for which they were designed. The feed-stock was prepared, the catalyst was mixed and the reactor pumps were started. Luckily for the manager of the plant, the preliminary work had been done well, and within a few weeks the plant was running smoothly, making RD 100 of the required quality and at the rate that had been expected. One might

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(left) Construction engineers and workmen move on to the site and the large operation of building a new chemical plant begins.
British Hydrocarbon Chemicals.



The chemical engineer's dream come true – when the finished plant starts to operate. Such a plant may cost many millions of pounds.
British Hydrocarbon Chemicals.



Once the plant has begun operating, there is still a great deal of work for the chemical engineer to do to ensure that it runs faultlessly.

think that the chemical engineer's job had now finished: the plant had been designed and built, and was running smoothly, but the plant manager still had plenty to keep him busy.

The job of a plant manager is very like that of a doctor. He has a patient, the chemical plant, which he can bring to life at will (some doctors would envy him in this), but which falls ill at times. He must be able to find out what is wrong from tests and measurements made on the plant and then apply the cure. His patient cannot talk, of course, but no one could fail to understand the howl made by a faulty turbine. The plant manager must also train and control the operators who actually run the plant, so that they understand the process and can correct the smaller upsets. However many automatic control devices are built into a plant, there is always the possibility that something will go wrong – a pump becomes overheated, a leak appears in a pipe, or a distillation column unaccountably fails to perform the task it has done steadily and efficiently for the past two years. In each case the plant manager has to be there to work out how the pump can be cooled down, the leak repaired without upsetting the rest of the process, or the distillation column made to behave. He also has to make sure that his plant produces the right amount of the right quality product at the right time, all in the most efficient and economical way possible – no easy task.

When the RD 100 plant had been running for a few years, an important contract was signed with a paint manufacturer who was planning to incorporate RD 100 in a new range of lacquers. This meant extra business to the tune of 5,000 tons a year and, as the plant was then running at its full capacity, the first of many modifications was carried out. The plant manager called in the chemical engineers in the technical department to help him. They were familiar with the plant, but

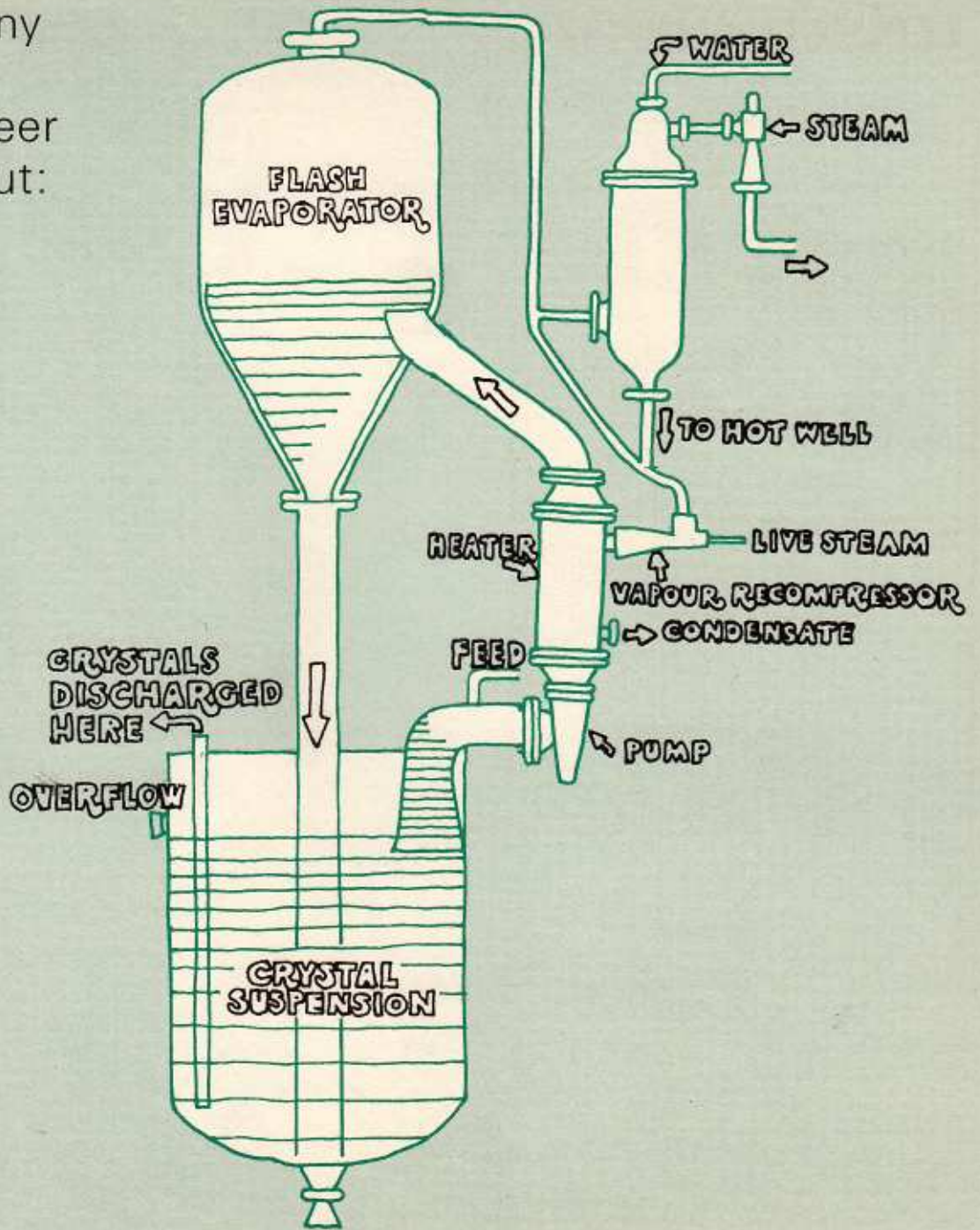
they were not concerned with the day-to-day details which occupied the manager. They took measurements at various points, arranged special runs so that various pieces of equipment could be tested, and calculated flows of materials and the pressures and the temperatures throughout the plant. After several months' detailed work, they produced recommendations for extending the capacity. By replacing heat exchangers with larger ones, putting different internals in some of the distillation columns, and making many other small modifications throughout the plant, its capacity could be increased to the required 15,000 tons a year. They were in the fortunate position of being able to make accurate measurements, whereas the original designers had very often had to guess, and they could therefore predict the behaviour of the plant with greater accuracy. The new equipment was ordered, and by carefully timing the engineering work so that it coincided with the normal shut-down period of the plant, the various changes were made with the minimum upset. Enlargements like these were repeated several times, as the market for RD 100 increased, until the original plant had almost disappeared behind rows of shiny new vessels.

So much had the plant been transformed that the general manager was recently wondering whether the time had come to start from scratch again and build a completely new plant. Then he noticed a report on his desk, entitled 'The manufacture and properties of RD 762'. On one corner was written in blue pencil 'I think we have a successor to RD 100 . . .'.

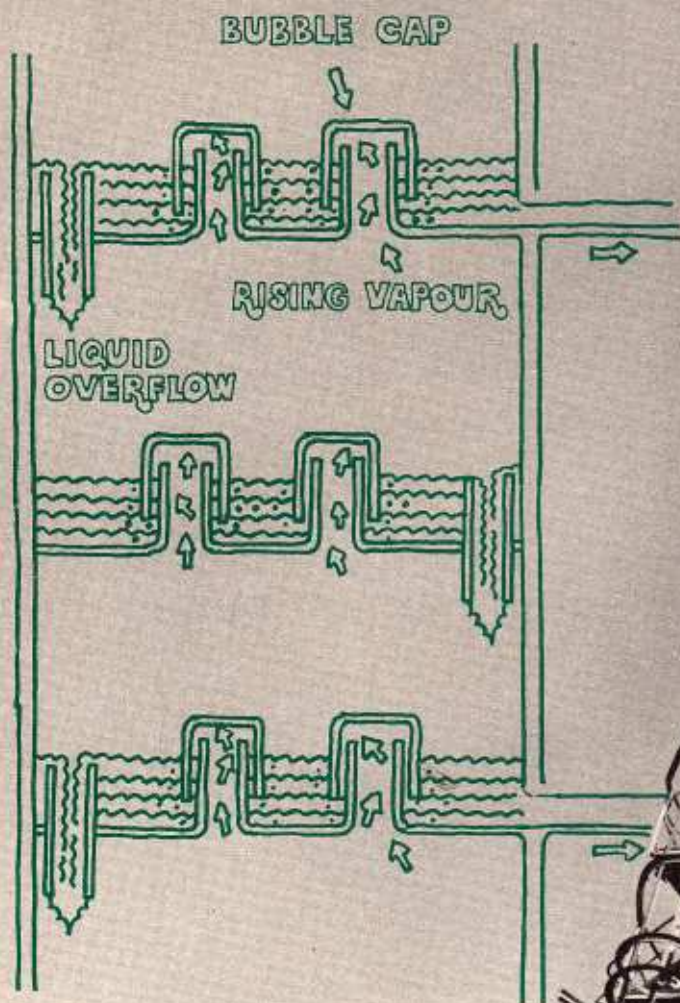
some of the many things that the chemical engineer must know about:

FRACTIONAL CRYSTALLIZATION

Purifying solid substances by crystallizing them from a suitable solvent. Shown here is an Oslo crystallizer, one of the many kinds used in industry. The main feature of this kind of crystallizer is that crystals are produced in a continuously flowing stream. The solution from the crystal suspension is first pumped through a heater, then into a flash evaporator before being returned to the crystallizer. Small nuclei form and circulate with the solution until they are too heavy for the current to carry them away from the bottom of the apparatus. The final product is removed entirely from the bottom of the crystallizer through the discharge pipe shown. The uniform product is obtained because crystals do not settle at the bottom until they have grown to the required size.

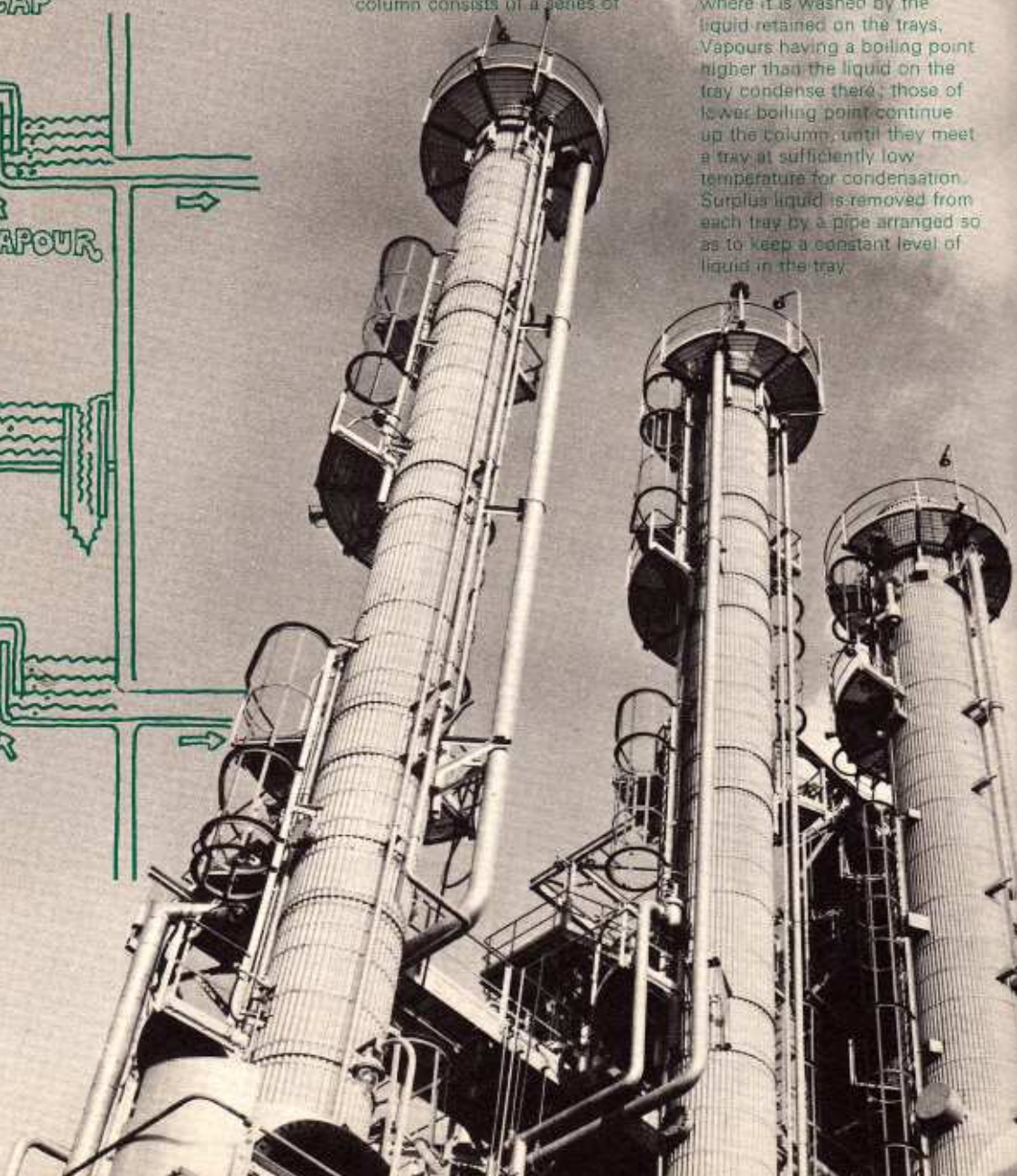


FRACTIONAL DISTILLATION



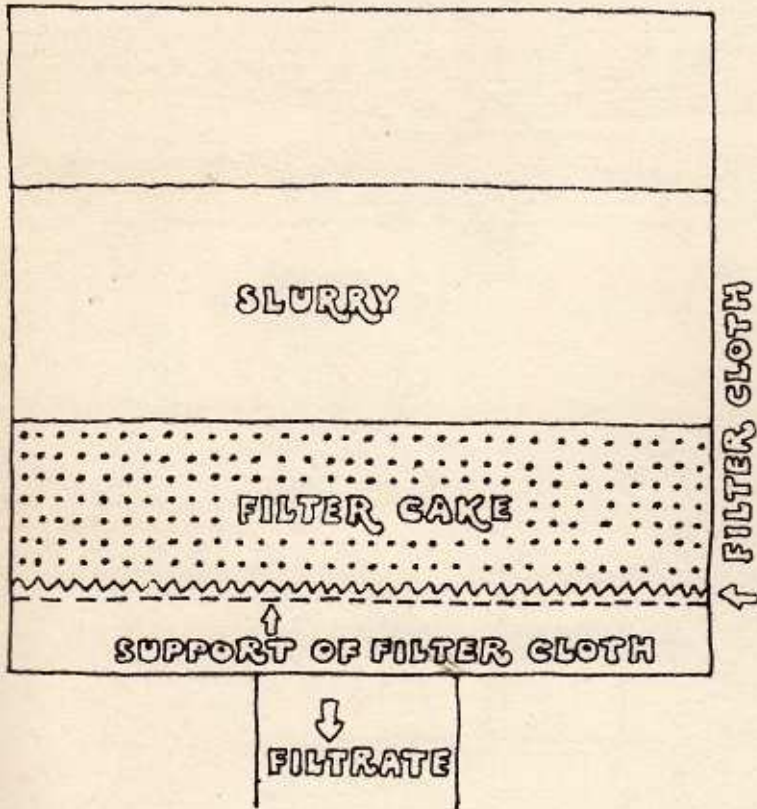
Separating a mixture of liquids by heating them and collecting the separated fractions from different levels in a fractionating column. The fractionating column consists of a series of

trays, each of which is at a temperature lower than the one below it. The mixture of vapours rising up the column passes through bubble caps, where it is washed by the liquid retained on the trays. Vapours having a boiling point higher than the liquid on the tray condense there; those of lower boiling point continue up the column, until they meet a tray at sufficiently low temperature for condensation. Surplus liquid is removed from each tray by a pipe arranged so as to keep a constant level of liquid in the tray.



FILTRATION

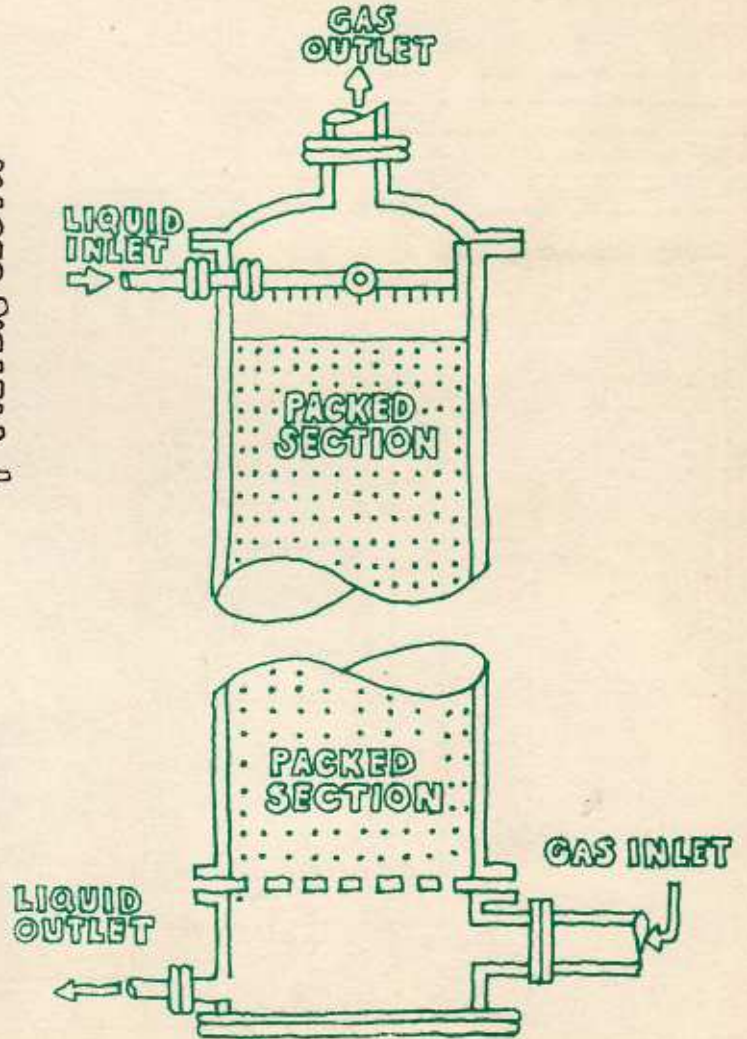
Separating a solid from a fluid by a porous medium which retains the solid (filter cake) but allows the fluid to pass.



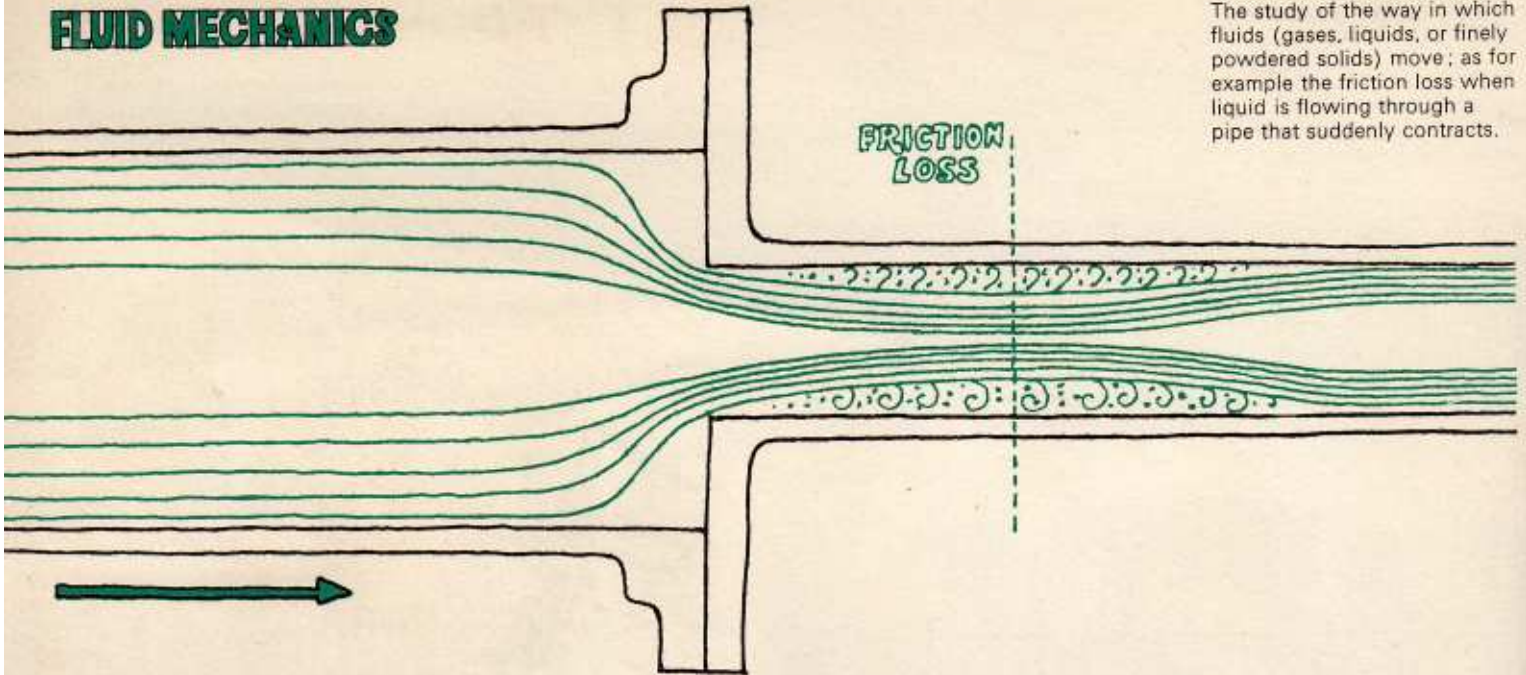
MASS TRANSFER

Involving the transfer of substances in various separation processes; as for example the separation of two gases (say, ammonia and air) by passing them through a liquid (say water) in which one of the

gases (ammonia) is soluble. This separation is often carried out in a tower packed with lumps of an inert solid through which the liquid slowly diffuses down and the gases up.

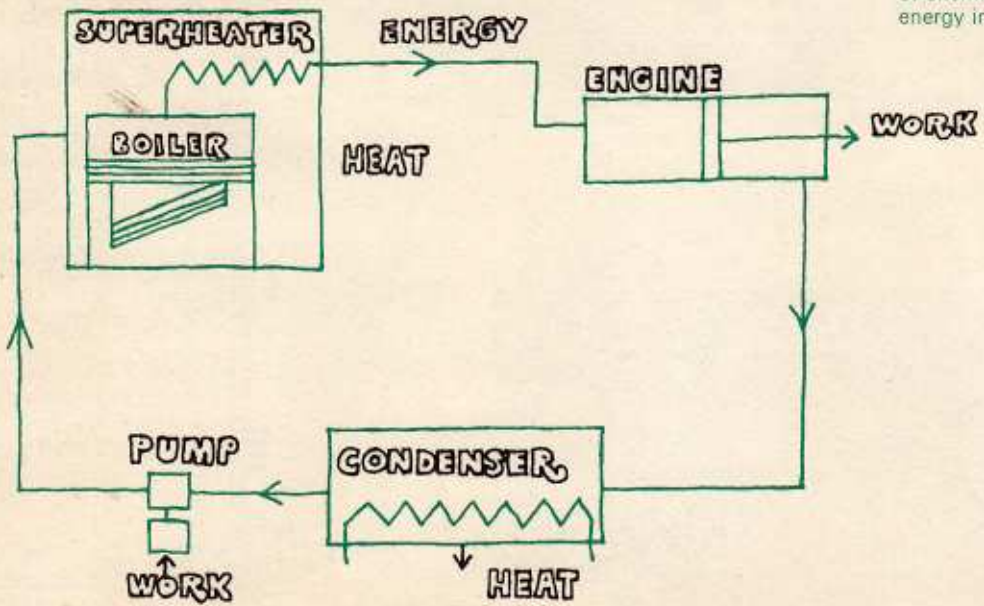


FLUID MECHANICS



The study of the way in which fluids (gases, liquids, or finely powdered solids) move; as for example the friction loss when liquid is flowing through a pipe that suddenly contracts.

ENERGY CONVERSION



The study of energy changes; as for example the conversion of chemical energy into heat energy in a steam engine.

HEAT TRANSFER

The study of heat loss and gain, as for example avoiding waste of heat in chemical reactions by using heat exchangers in which the heat from the products is transferred to the incoming reactants or used to heat water.

