other means can approach. Objections and questions can be dealt with immediately and all relevant information is normally accessible. But the personnel of this advisory service is regarded as highly important. The research worker himself may not be the best man for the job ; indeed it is seldom that the scientific worker has had the time or opportunity to acquire that thorough first-hand experience of the land which counts so much in farming circles. The type of man chosen for this work should therefore be perfectly sound on the practical side, with sufficient experience of management to be able to regard a proposed course of action from the farmer's point of view. He must also have enough scientific knowledge to understand the work of the research department and explain its more practical aspects to those who would have to apply them.

Next in importance comes the demonstration farm, where technical improvements may be seen in operation alongside the older methods. The effect is often convincing, but the improvement must always be regarded in its agricultural context, and may have to be modified under expert guidance to suit some local set of conditions. This method is being used with considerable effect by the County War Agricultural Committees, who have set themselves the task of putting up straightforward illustrations of improved methods throughout their areas. A demonstration by itself can seldom be entirely satisfactory ; it should have competent demonstrators, and the resulting informal discussions on the headland of the field provide perhaps the most convincing type of farmers' lecture.

Farmers are not great readers ; certainly not of the more scientific journals or even of the popular expositions of agricultural research. The limited number who are in close touch with science and education or are active supporters of the leading agricultural societies are in no way typical of the general body. For wide consumption accounts of new methods must be written in a very direct style shorn of scientific technicalities. Official bulletins, the weekly agricultural Press and, in expert hands, the local Press, can do good work in this direction. Farmers should feel, however, that they have always some specialist within reach who would discuss and amplify information derived from these sources.

In most matters relating to British agriculture the tendency is to make comparisons, sometimes rather unfavourable, with the achievements of the Dominions or foreign countries. Lord Bledisloe, in his opening survey of the position of agricultural research and advisory work in the many countries of which he has had first-hand knowledge, certainly gave the impression that, on the whole, agricultural information is more widely disseminated and more readily received elsewhere than it is in Great Britain. Some of the reasons for this, such as a more fixed agricultural policy and more general technical education, have already been mentioned. In addition, in many countries agriculture has been a much more vital concern than in Great Britain before the War, and, in the Dominions at any rate, the race of farmers have a shorter background of traditional methods, and consequently feel less settled in their ways. Most of the methods of disseminating knowledge used elsewhere appear to have their close counterparts here, although it is possible that in Great Britain they may be handled with less vigour and effect. It was pointed out that our agricultural education, being planned on a county basis, is often uneven in quality, the wealthier and possibly less agricultural counties being in a position to spend more than the others. There is room here for some form of central finance and direction that will make for a more uniform standard. This point was elaborated by Dr. Slater, who suggested that there should be one national service for the dissemination of scientific information under a technically trained director who would control both the advisory and the county staffs, maintaining the scientific standard of the former and the quality of the instruction given by the latter. He would foster collaboration between the two branches, and maintain close contact with the research institutes. Because a system is successful abroad it by no means follows that it is best for British conditions ; nevertheless, the feeling was that the methods employed in northern Europe might well repay study by a travelling mission.

There is no doubt that the activities of the County War Agricultural Committees will have a great influence on the dissemination of technical information to farmers in Great Britain. In many cases their problem is to grade up the weaker farmers towards the level of the better ones : not so much of developing new knowledge but rather of bringing into general acceptance the methods that have been practised on progressive farms for years. In duties of this kind the committees must have obtained a clearer and much more detailed picture of the state of English farms and the technical needs of English farmers than ever before. In the discussion, certain speakers advocated the retention of the agricultural committees in some modified form after the War. However this may be, the large body of workers now engaged on advisory work on behalf of the committees are building up a body of knowledge and experience that should be invaluable when, as we hope, science will have to serve practice in a planned post-war agriculture.

RECENT PROGRESS IN HEAT TRANSFER*

By PROF. C. H. LANDER, C.B.E.

LINKING theory with practice is always beset with difficulties, and in no branch of engineering science are these greater than in heat transfer. In a modern boiler, for example, heat is conveyed from the fuel to the water-tubes by direct radiation from the firebed, and from incandescent soot particles, carbon dioxide and water vapour in the furnace gases, as well as by reflected radiation from surrounding refractories, and by convection from the gases. The rational approach to such a complex set of conditions is undoubtedly first to determine the fundamental laws of radiation, convection, etc., and then to apply them in building up a picture of what is happening in the actual furnace. Ways of improvement can then be foretold, and new designs worked out.

The fundamental laws of heat transfer are now fairly well known, but appliances involving heat transfer are still designed largely by trial and error, and any departure from traditional design is still

* Substance of the opening paper at a discussion at the Institution of Mechanical Engineers on April 24.

viewed by m. .ny with apprehension. While it is no doubt true that the quickest way to design an appliance that will work is usually to follow well-tried principles, it is only by persevering with attempts to rationalize our knowledge that the best use can be made of science, and the engineer given the fullest help in his struggle towards increased efficiency.

Since radiation and convection are distinct phenomena, obeying different laws, they must be treated independently; and it is convenient also to consider separately heat transfer to evaporating liquids, and from condensing vapours, although they both bear a relation to convection.

Radiation and Emissivity

In heat transfer problems, the engineer is concerned only with the radiant energy emitted by all matter with increasing intensity as its temperature rises, commonly known as 'heat radiation'. The laws of black-body radiation are well known, but numerical calculations entail a knowledge of emissivity, which, since most actual surfaces are selective emitters, changes with temperature. Nothing like a full range of values has yet been determined, and the exact condition of industrial surfaces often cannot be specified.

There is still much to be learned about the selective emission of hot gases and flames. Water vapour and carbon dioxide, being products of combustion of all ordinary fuels, are of particular interest. Schack, in 1924, attempted calculations from infra-red absorption data, but there was so much uncertainty about the limits of the absorption bands, and the variation of the coefficient of absorption within them, that probably the most important outcome of his work was that it led others to make direct measurements. Their results agreed well for carbon dioxide, but were at variance for water vapour. Emissivity was given for different values of the product of the partial pressure and the thickness of the gas layer, and so tacitly assumed that the radiation depends only upon the total number of radiating molecules, and not upon whether they are spread out over a thicker layer with a smaller partial pressure, or compressed into a thinner layer with a higher partial pressure. Eckert and McCaig independently, however, have shown that for water vapour, although not for carbon dioxide, the emission may depend to a considerable degree upon the partial pressure and thickness of the gas layer separately, as well as upon their product.

In industrial plant, with flue gases, or gases containing steam, gas radiation may far outweigh convection. Thus Fishenden, measuring directly the heat transfer from the products of combustion of town's gas, flowing at 2–3 ft. a second through a 1-ft. pipe, found gas radiation varying from three times convection at 1,000° F. to ten times at 2,000° F. Admittedly, the velocities were low, but at higher temperatures, such as are found in many industrial furnaces, the relative importance of gas radiation rapidly increases.

So far, no really systematic experiments have been made on the emission from luminous gases or flames. If the suspended particles causing the luminosity are opaque, the emission, like that for non-luminous radiation, increases according to an exponential law, but for particles small enough to be partially transparent the case is much more complicated. There have been various attempts to evaluate furnace radiation, or to devise instruments for measuring it, but only on arbitrary and empirical lines.

Convection

The recent development of dimensional methods of correlating convection data has widened their range of application, and so greatly accelerated progress. Thus, experiments under pressure with surfaces only a few inches high may be used to deduce the heat transfer from surfaces several feet high at atmospheric pressure; or experiments in gases may be used to deduce the heat transfer in liquids. The most important dimensionless groups used in heat transfer are as follows:

The *Reynolds number* or Re, Vl/ν, or (velocity × characteristic linear dimension)/(kinematic viscosity), which determines the distribution of velocity in a stream of fluid flowing past a surface.

The *Prandtl number* or Pr, $c\nu/k$, or (specific heat per unit volume at constant pressure × kinematic viscosity)/(thermal conductivity), which determines the distribution of temperature in a fluid, the distribution of velocity already being given by Re. For example, in flow through a pipe, the velocity distribution is determined by Re, the temperature distribution by both Re and Pr.

The *Grashof number*, or Gr, $ag\theta l^3/\nu^2$, or (coefficient of expansion × gravitational constant × temperature difference × cube of characteristic linear dimension)/(square of kinematic viscosity), which is used only in natural convection, where, together with Pr, it determines the distribution of both velocity and temperature.

The *Nusselt number*, or Nu, $Hl/k\theta$, or (heat transfer per unit area per unit time × linear dimension)/(thermal conductivity × temperature difference).

Natural convection. Saunders has shown that theory suggests a satisfactory correlation of natural convection data by relating Nu with $Gr.Pr$, since, although there is actually a slight residual effect of Pr, this is negligible except in the extreme case of mercury, for which Pr is exceptionally low. Experiment amply confirms this, and curves are now available over a wide range for vertical and horizontal planes, and vertical and horizontal cylinders.

The transfer of heat across a layer of fluid between a hot and a cold surface is an interesting case of natural convection. By plotting the ratio of actual heat transfer to calculated conduction the results for gases and liquids can be correlated. The results for parallel vertical surfaces, and for concentric horizontal or vertical cylinders, lie on the same curve, provided the ratio of outer to inner cylinder diameter is small, say less than about five.

Forced convection: Flow across banks of tubes. Data on heat transfer and pressure drop in the flow of gases across banks of tubes are vital in designing efficient economizer and superheater units, as well as many types of forced-circulation boilers and heat interchangers. The first systematic investigation was by Reiher in 1925. He measured the total heat transfer and pressure drop for two spacings of tubes, and for both 'in-line' and 'staggered' formations. His work, however, did not cover a wide enough range for deducing general laws, and it was not until Pierson, Huge and Grimison's work in 1937 that satisfactory correlation became feasible. It has now been shown that the heat transfer can be closely related to the velocity in the narrowest restriction between the tubes.

The designer will usually be concerned with obtaining the greatest possible heat transfer for a given pressure drop. For a given mass flow, the lower the velocity, the smaller the pressure drop, and the smaller also the heat transfer for any given surface. Hence a compromise is necessary between the limitations of pressure drop and of space.

Heat Transfer and Fluid Friction

Osborne Reynolds, in 1874, pointed out the analogy between the transfer of heat and the transfer of momentum through an eddying fluid. Recently, with the conception of a more or less stationary film of fluid in contact with the surface, it has been realized that Reynolds' theory must be modified to take account of the two successive stages of heat transfer, first through the stationary film by conduction, and then into the core of the fluid by turbulence.

Boiling Liquids

Three distinct stages are now recognized in the boiling of liquids. The first stage, in which there is no appreciable bubbling, corresponds to the heating-up process before the boiling point has been reached. In the second stage, chains of bubbles rise from the heating surface, their sweeping and stirring effect increasing with the violence of the boiling. As the temperature difference is increased, there comes the third stage, in which the vapour bubbles tend to merge, until they may ultimately form a continuous layer over the heating surface. In the first stage, the heat transfer can be calculated from the appropriate convection data. In the second, or bubbling, stage, the heat transfer is relatively very high, and increases with the temperature difference until the final, or 'film', stage is approached. A sharp decrease then occurs, owing to the blanketing effect of the vapour layer. Hence, there is an optimum temperature difference, which depends upon the nature and condition of the surface, and particularly upon whether or not it is wettable.

Experiments on boiling liquids are of exceptional difficulty for, if the load is high, there may be considerable temperature differences both through, and over the surface of, even metal heating surfaces. Moreover, surface conditions, which greatly influence the rate of heat transfer, may change with time. Thus it is not surprising that no altogether satisfactory correlation of the experimental data has yet been achieved, although many attempts have been made. Surface tension and viscosity, however, are known to be important factors.

Condensing Steam

Nowadays, in designing condensers and evaporators it is essential to know the heat transfer coefficients from condensing steam. The condition of the surface is a very important factor. On a rough surface, free from grease, the condensate spreads out in a continuous film; but on a smooth, greasy surface it tends to form in separate droplets, giving five or ten times the heat transfer of a film. Consequently, much interest is being shown in finding effective 'promoters' of dropwise condensation.

Small proportions of air in steam, by introducing an additional thermal resistance, greatly reduce the heat transfer.

Conclusions

During recent years the engineer has looked more and more to fundamental science for help in his problems of design and working, and, on the other hand, the pure scientist has shown an increasing readiness to admit the importance of industrial applications. Although in full-scale plant, even when scientifically controlled, the conditions can never be specified with the accuracy possible in small-scale laboratory apparatus, key calculations can often give the designer a valuable pointer in deciding what changes are most likely to lead to improved results. There are still many gaps to be bridged, both in basic knowledge and in methods of using it, but much real progress has been made.

OBITUARIES

Prof. W. J. Young

PROF. W. J. YOUNG, whose death occurred recently in Australia, was best known for the work on the breakdown of carbohydrate by yeast which was carried out in conjunction with the late Sir Arthur Harden between the years 1904 and 1913.

The classical researches of Harden and Young on the fermentation of carbohydrate by yeast established the phosphorylation of carbohydrate as an essential stage in the conversion of sugar to alcohol and carbon dioxide, and finally Young successfully accomplished the isolation of a hexose diphosphate. A quantitative relation was demonstrated, the amount of carbon dioxide liberated being proportional to the amount of inorganic phosphate which disappeared from the solution. The process of phosphorylation thus established as essential for the breakdown of carbohydrate by yeast was later shown by Embden and his colleagues to be also a necessary stage in the transformation of carbohydrate to lactic acid carried out by the muscle cell of the animal organism, and by Robison to play an important part in the ossification of cartilage. Harden and Young had laid the foundations of carbohydrate biochemistry, when they showed that it is by the process of phosphorylation that the living organism changes the starch and sugar molecules into the simple substances which are their final products.

After nearly ten years of fruitful co-operation with Harden, Young accepted the post of biochemist to the Institute of Tropical Medicine at Townsville, Australia, and left the Lister Institute. Some years later he was appointed professor of biochemistry in the University of Melbourne. There he became greatly interested in the teaching of biochemistry and built up a very fine department, paying special attention to the needs of medical students. His published papers during this period were concerned chiefly with the natural products of Australia and with problems brought to him for investigation.

Young was a man of wide interests and nothing gave him more pleasure than a friendly argument with his colleagues on every variety of subject. He was keenly interested in politics; and whatever subject he followed he devoted himself to it with enthusiasm, whether it was carbohydrate chemistry or the game of golf.

He will be remembered with affection by his former colleagues at the Lister Institute. He leaves a widow and a daughter, Sylvia, now practising medicine.

I. SMEDLEY-MACLEAN.