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Service Results with High Pressure Boilers.

READ

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CHAIRMAN: Mr. R. RAINIE, M.C. (Chairman of Council).

Synopsis.

THIS paper attempts a review of the performances of some modern boilers, and is largely based upon information presented by the boiler manufacturers. It deals entirely with boilers in which a departure is made from natural circulation and attempts to discuss the fundamental principles underlying the design of each type. A brief statement is made of the way in which the modern boiler has developed during recent years and of the general approach to high-pressure and high-temperature steam production. Attention is drawn to the fact that if very high pressures are to be used, then interheating with its increased complication of circuit must be adopted. In connection with the production of steam at high pressure and temperature the importance of purity of feed water and the question of steam drums are touched upon. Considerable attention is given to the question of heat transmission, and the effect of gas temperature and velocity upon the conditions in the tubes is dealt with. This is followed by somewhat detailed discussion of the La Mont, Velox, Loeffler, Sulzer, Benson and Schmidt-Hartmann boilers.

This paper is an attempt to review a number of modern marine boilers, each of which has some special claim for recognition as a plant suitable for high pressure and temperature conditions of operation. The information to be given has been supplied by the manufacturers, and it is hoped that in what follows, this information will be presented in such a manner that the particular features and claims of each boiler type will be readily recognised.

Before commencing the descriptive work, it will be necessary, however, to make a few preliminary remarks upon some of the fundamental features associated with boiler design, in order that the reasons for the special features presented by these new steam generators may be appreciated.

Turning for a moment to land practice, it has been evident for a number of years that the pressure and temperature conditions of modern power plants are becoming more and more severe. The tendency is perhaps more marked in the United States of America and on the Continent than in this country, but even at home there are several examples of stations to be found in which the working conditions are sufficiently high to satisfy the most fervent supporter of the claim that maximum economy of power producton is associated with the highest possible conditions of pressure and temperature.

Along with the pressure and temperature development there has also been a steady movement towards an increase in the evaporative power of each boiler unit, so that we now have examples in land central stations of steam generators each capable of producing up to one million pounds of steam per hour at pressures and temperatures in the neighbourhood of 1,300lb. per sq. in., and 900° F. respectively.

Accompanying the pressure and temperature increases there have been changes in general design until we now have the modern land boiler with its furnace completely surrounded by tubes containing water (or steam) and with its separate constituent parts of superheater, evaporator, economiser, and air preheater. The feature to be chiefly noted is the modern type of combustion chamber which has developed to its present condition largely from the use of pulverized coal firing. In early examples of such firing the deterioration of the brick lining of the combustion chamber was so rapid that water tubes were first arranged around the walls, in a somewhat elementary fashion, in order to afford some protection to the brick lining. The encouraging results of this treatment, as shown by the greatly increased life of the furnace lining, led to a more rational design of the "water walls" and ultimately to an appreciation that what was originally chiefly a safety device could be made to serve as one of the most valuable parts of the heating surface. It is probable that in the combustion chamber of a modern land boiler, lined on all six sides with water tubes and burning pulverized fuel, the heat transmitted mainly by radiation to the water ranges from 45 to 60 per cent. of the calorific value of the fuel.

The addition of an air preheater was due mainly to the introduction of stage feed heating, which, in its turn, was introduced to improve the efficiency of the working cycle, and also to relieve the low pressure stages of the turbines from some of the working steam. With the high feed water temperatures thus available, some means had to be found for bringing down the flue gas temperatures, and consequently an air preheater was fitted so that the gases before passing to the chimney could give up some of their heat to the combustion air.

In what is to follow it will be noticed that all of the features just described as belonging to the modern land boiler will also be found in the boilers which are gradually finding their way into marine service. The use of high pressure and temperature is especially remarkable since it will be found that, contrary to the general predictions made some years ago, pressures and temperatures as high as those adopted in land practice are now being employed in marine installations. If, however, very high pressures are to be employed, then the fact must be faced that reheating will be necessary, and that a further complication will be added to the ship's machinery. As the steam expands in the turbine it first loses its superheat and then becomes wet. It will be found that for a given exhaust pressure the final wetness will increase as the initial pressure rises. Thus with an initial pressure of 2,000lb. per sq. in., and the steam superheated to 900° F. frictionless adiabatic expansion to a 29in. vacuum would produce a 26 per cent. wetness at the exhaust pressure. With an initial pressure of 500lb. per sq. in. expansion under the same conditions would result in an exhaust wetness of 17 per cent. In actual cases, due to the influence of stage losses, the final wetness would be appreciably less than is indicated by the figure just quoted, but the necessity for reheating the steam at some stage of its expansion when high pressures are used will be readily accepted. The problem then is whether to make the reheater part of the boiler and to extract heat from the flue gases, or whether to use the high pressure steam in a heat exchanger to raise the temperature of the expanding steam to such a temperature that it will not become more than 10 to 12 per cent. wet at the exhaust pressure. On land both systems are adopted, but at sea, so far as reheating is practised or suggested at present, the steam reheater appears to be the one proposed. In this connection it may be of interest to refer to the reheating installations fitted in the s.s. "Lancaster Castle" and the s.s. "Lowther Castle". In these vessels steam leaves the boiler at a pressure of 220lb. per sq. in. and a temperature of 750° F. and before entering the h.p. cylinder passes through a steam reheater where its own temperature is reduced to about 600° F. and the temperature of the exhaust from the h.p. cylinder is raised to over 550° F. Here the boiler pressure is only moderately high, and prudence suggests the use of a fairly modest amount of superheat for a reciprocating engine, but the fact that interheating is in use at sea is another indication that the terror of departure from the ordinary, so evident in marine engineering circles, may be now disappearing. The reheating proposal made in connection with a Loeffler installation will be considered later.

It might now be appropriate to consider what influence the use of high pressure and temperature will have upon the design or running of the steam generating plant. In the first place it would seem essential that special attention should be given to the purity of the feed water. Under the high temperature and the high heat transmission rates to which the majority of the new boilers are subjected, cleanliness of the water or steam sides of the heating surface is essential. It will be interesting to consider if in this particular feature there is any difference in the requirements of individual examples of the new types of boiler, and whether in any case the design of the boiler makes it less sensitive to impurities in the feed.

The question of the steam drum is also one of special importance. Under modern high pressure conditions the riveted drum is fast disappearing; solid forged drums are largely used, and there are now many firms who look upon the welded drum as standard practice. While these latter methods of construction greatly lessen the difficulties associated with riveted joints in thick plates, yet it must be realised that even in a forged or welded drum of non-symmetrical section serious stresses may be set up which are not disclosed by the usual simple methods of calculation used for stress determination in circular vessels. For instance, the lower half of a steam drum may have to receive the water tubes, and in consequence it will be thicker than the top half. In such a case, due to the non-uniform thickness, bending moments are set up which produce stresses much in excess of those estimated in the usual way for cylinders of uniform thickness. There is also the possibility that part of the drum surface may be at a temperature appreciably higher than that of the rest of the surface. In such circumstances additional stresses will be set up which in very high pressure boilers must be taken into account. As an example a case came before the author in which the lower half of the drum of a water-tube boiler was one inch thicker than the other half. In addition there was a fairly large temperature difference between the inner and outer surfaces of the metal, due to the proximity of the lower half of the drum to the furnace gases. When the induced bending moments due to the non-symmetrical section and the heat stresses were taken into account, it was found that the actual stresses were over 50 per cent. greater than those estimated by the usual simple theory.

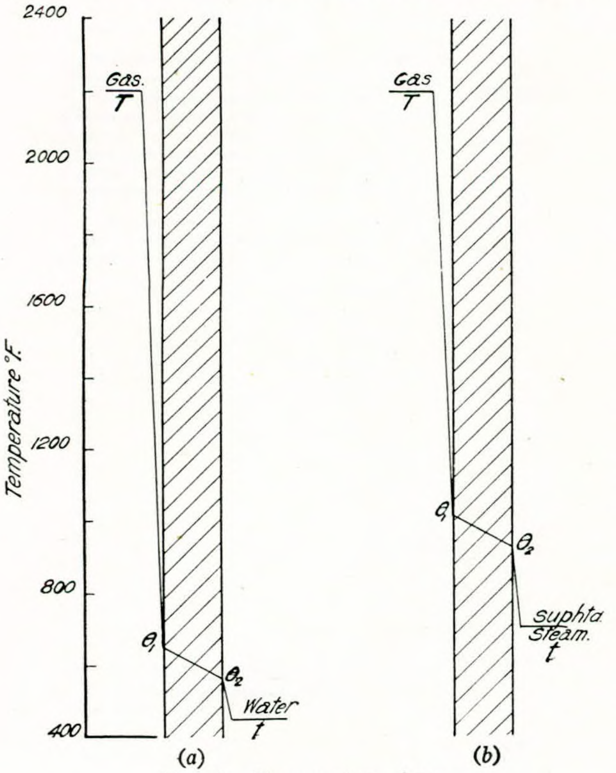

FIG. 1.—Temperature drop.

Heat Transmission.—Before approaching the detailed consideration of individual boilers some consideration must first be given to the manner in which the heat from the combustion gases is transferred to the heating surface and passed on by that surface to the water or steam circulating through the plant. The importance of an understanding of the heat exchange problem cannot be exaggerated, and indeed some of the steam generators to be described would not have been possible unless those responsible for their design were familiar with the mechanism of heat transmission. The extent of the radiant heat transmission in the modern boiler has already been indicated, and much work has been done within recent years in researches upon the laws of furnace radiation. As a general rule it may be stated that the amount of heat, Q, absorbed through radiation by the comparatively cold walls of the heating surface may be expressed by $Q = C\ (T^4 - \theta^4)$, where T is the absolute temperature in the combustion chamber, θ the absolute temperature of the absorbing surface, and C a coefficient which varies with the circumstances. Obviously the dominating influence is the furnace temperature, and high or low values of heat release will largely depend upon the complete or incomplete combustion of the fuel and upon the amount of combustion air.

It has already been mentioned that, with pulverised fuel firing, and in a combustion chamber lined on all sides with water tubes, the heat transmitted to the heating surface varies from 45 to 60 per cent. of the calorific value of the fuel. The whole of this heat (except for external losses) must pass through the metal walls of the tubes by conduction, and from the walls to the water or steam by convection. Some idea of the way in which the gas to water exchange takes place may be obtained by reference to Fig. 1 (*a*) where is shown the approximate relationship between the temperatures of gas, metal and water during the process of evaporation.

Considering first the heat transference through the metal, it will be obvious that the amount of heat transmitted per unit of surface in unit time will depend only upon $(\theta_1 - \theta_2)$. For the normal boiler $(\theta_1 - \theta_2)$ is comparatively small, and estimates show that if heat is being transmitted through an ordinary carbon-steel tube, $\frac{1}{4}$in. thick, at the rate of 10,000 B.Th.U. per sq. ft. per hour $(\theta_1 - \theta_2)$ will be from 5° to 6° F.

This temperature drop through the metal depends, however, directly upon the coefficient of conductivity of the material from which the tube is made, and it is rather unfortunate that this coefficient for alloy steels is much less than that for plain carbon steels. Taking the coefficient of conductivity K, as measured in B.Th.U. per sq. ft. per min. per ° F. per in. thickness, the average values at 212° F. for different materials are given as follows :—

For 0·26 carbon steel, 6·46; for a carbon steel with 0·5 per cent. molybdenum 4; for stainless iron, 2·9; and for 18/8 chromium nickel steel, 1·9. It is now common practice to use a molybdenum steel for the high superheats now in daily use, and consequently the temperature drop through the metal for a given heat transfer rate would be more than 50 per cent. in excess of that required with a plain carbon steel. It is necessary to keep in mind this temperature difference between the outer and inner surfaces of the tube, since its effect upon the tube stress is very marked with high rates of heat transmission.

It is rather strange that the laws relating to the transfer of heat, under convection conditions, from the fluid to the plate on one side, and from the plate to the fluid on the other side have been, until comparatively recently, little appreciated by practising engineers. The first real exposition of these laws was presented by Prof. Osborne Reynolds in a paper read before the Literary and Philosophical Society of Manchester in 1874. In his treatment Reynolds pointed out that, apart from radiation, the quantity of heat imparted by or to a fluid to or from an adjacent surface was proportional to the rate at which particles or molecules pass backwards and forwards from the surface to any given depth within the fluid. For conditions usually present in a boiler he claimed that the heat H transmitted per unit surface per unit time could be expressed by $H=B_1\rho_1 v_1\ (T-\theta_1)\ =B_2\rho_2 v_2\ (\theta_2-t)$ where ρ is the density, v the velocity of the fluid, and B a coefficient depending upon the nature of the fluid. If the transfer from gases to water is being considered, the subscript 1 would refer to the gas conditions, and 2 to the water conditions. For design purposes, it is often more convenient to change the formula to $H=B_1\ \frac{w_1}{a_1}\ (T-\theta_1)\ =B_2\ \frac{w_2}{a_2}\ (\theta_2-t)$; where a is the area for fluid flow and w is the weight of fluid passing through this area in unit time.

It has been shown by experiment that water is easily capable of taking from the heating surface all the heat that the gases can put into it, and that once the water is circulating over the surface, increase of water velocity has little effect upon the heat transmission rate. It must be remembered, however, that this refers to water only, and not to mixtures of water and steam. With high rates of heat transference evaporation will take place rapidly, and in all cases the exit ends of the tubes will contain a water-steam mixture. If too little water is present overheating will take place unless the velocity is sufficiently high. The importance of a positive controlled circulation where high heat transmission rates are required is clearly indicated.

After this brief review of general conditions it is now possible to examine in detail some of the modern types of steam generators and to contrast in some degree their methods of operation. It will be generally recognized that in all examples the aim of the designer is to produce boilers capable of generating with safety steam at high pressures and temperatures, and, in comparison with the older types, with less weight and volume. To secure the reduction of heating surface, high gas speeds, intense radiation effect and controlled positive circulation of the water and steam are employed; for reduction in combustion chamber volume, high rates of heat release are aimed at.

La Mont Boiler.

A diagrammatic sketch of the La Mont boiler is shown in Fig. 2. From this it will be seen that its characteristic feature is the forced circulation of the water through the evaporator tubes. The feed water passes through the economiser in the usual way, and is delivered below the water level to the steam drum. From there it is taken by a circulating pump, and forced through the tubes which line the combustion chamber, back into the steam drum. During its passage through these tubes the steam is generated, and it is a mixture of water and steam which is delivered to the drum above the water level. The steam separates out and passes to the superheater where it receives its heat from the partly cooled gases by convection. The pump, which is of the usual centrifugal type, is designed to give a circulation equal to about eight times that delivered by the

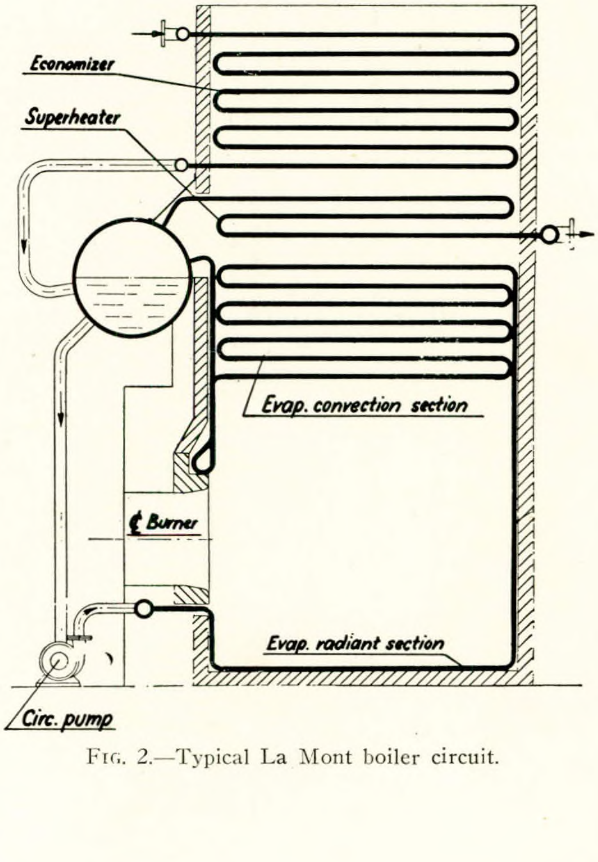

Fig. 2.—Typical La Mont boiler circuit.

feed pump, and runs at constant speed whatever the variation in the boiler output. An interesting feature of the design is the manner in which the quantity of water passing through each tube can be proportioned to the evaporation duty it has to perform. As will be seen from Fig. 2 the circulating pump delivers the water to a distribution header, into which the tubes are expanded. At the entrance to each tube adjustable orifices are fitted, and these can be of such dimensions that each tube receives its proper share of the forcibly circulated water.

The temperature conditions in these tubes are shown approximately in Fig. 1 (*a*) where a furnace temperature of 2,200° F. is assumed, and a boiler pressure of about 400lb. per sq. in. A very high rate of heat transmission, equivalent to about 90,000 B.Th.U. per sq. ft. per hr. is also assumed, and the temperature drop through the metal is estimated from a co-efficient of conductivity, K, equal to 4. Actually θ_1 will be less under these conditions than is shown in the figure since, due to the forced circulation, it is possible to use one inch internal diameter tubes of mild steel, a material whose conductivity is at least 50 per cent. greater than that selected for the calculation. This diagram will show that overheating of the tubes under such conditions is impossible, and that heat transmission of very high rates may be attained with comparatively low wall temperatures.

It will be obvious that by the use of small tubes and forced circulation the work of the designer is rendered much more simple, since it is possible to arrange the heating surface around the combustion chamber in any manner that is thought desirable without being troubled

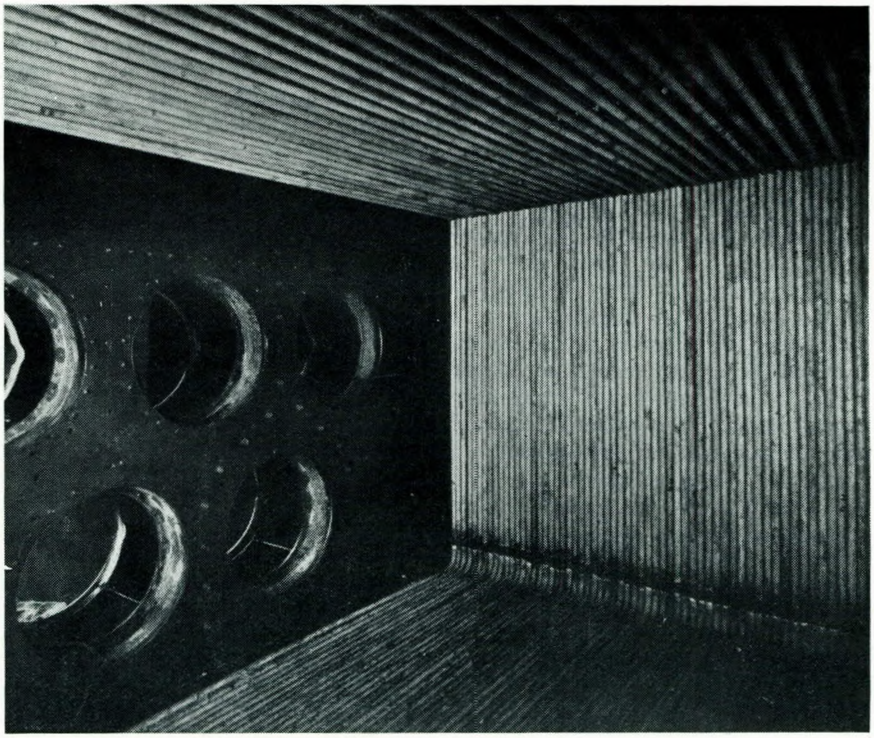

FIG. 4.—View inside combustion chamber of La Mont boiler, showing water-lined wall and floor, convection bank (at top) and burners.

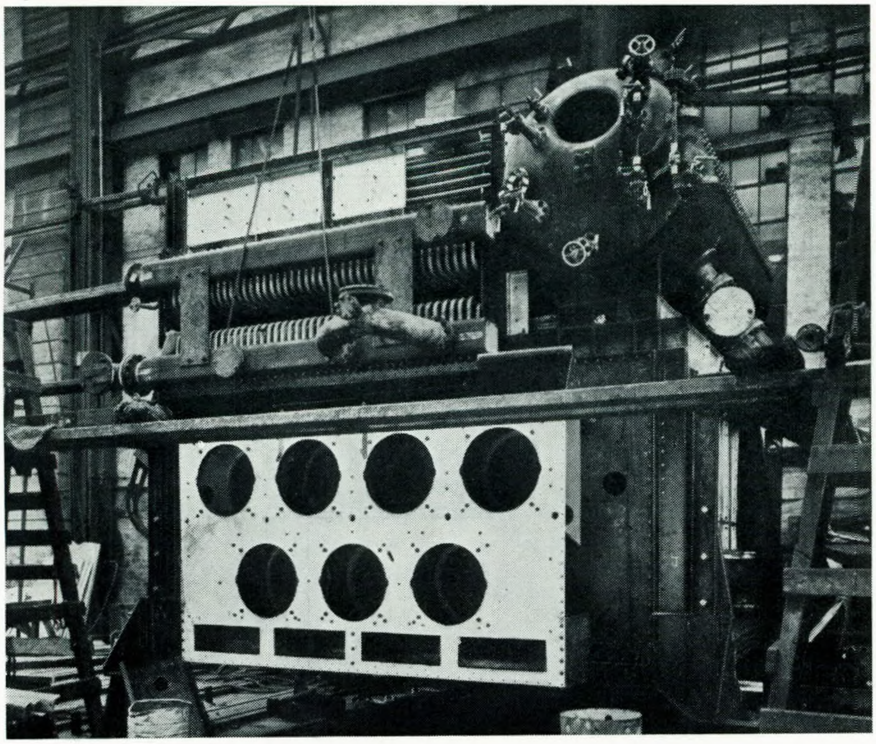

FIG. 3.—External view of La Mont boiler.

with possibilities of steam pockets. This is an important point as there are occasional reports of failures in some of the huge modern land boilers, with their complicated arrangement of water walls and natural circulation, due to over-heating.

Illustrations of a La Mont boiler built for the British Admiralty and fitted in one of H.M. destroyers are shown in Figs. 3 and 4. The general appearance will be gathered from Fig. 3, where the relationship of the steam drum to the circulating tubes is clearly shown. In Fig. 4 the construction of the combustion chamber lining is indicated, and especially to be noted is the manner in which the tubes by touching each other form complete water walls. The superheater tubes can be seen in the upper part of the boiler (Fig. 3), but it must be pointed out that no economiser or air preheater is provided in this plant.

The figures given below represent the shop trial results taken before the boiler was installed in the ship :—

Working pressure. lb. per sq. in. ...	290
Steam generated. lb. per hr.	105,680
Feed temperature deg. F.	211
Steam temperature deg. F.	688
Combustion chamber temp. deg. F. ...	2,733
Uptake temperature deg. F.	763
Efficiency (on upper C. V.) per cent....	73·1
Evaporation per ft.^{2} of boiler surface } lb. per hr. ...	21·1

The absence of economiser and air preheater accounts for the high uptake temperature and for the comparatively low thermal efficiency. From other figures supplied it is shown that the heat liberation per cubic foot of combustion chamber volume reaches the very high figure of 230,000 B.Th.U. per hour.

The European development of this boiler commenced in 1928 and since then over 450 installations have been ordered. Of the marine boilers the majority have been installed in a foreign navy, but at the present moment a number are under construction for merchant vessels, both on the Continent and in the Far East.

Velox Boiler.

This boiler is of special interest, since it not only employs forced circulation of the water, but by carrying out combustion at a pressure well above that of the atmosphere, a very high rate of heat liberation per cubic foot of combustion chamber volume is possible. Whilst high rates of heat transmission can effect a great reduction in heating surface, yet it has often been pointed out that the necessary volume of the combustion chamber fixes, to a large extent, the space occupied by the whole boiler. This is especially noticeable in the modern land boiler using pulverized coal firing, where in modern American practice the average rate of heat liberation per cubic foot is only of the order of 30,000 B.Th.U. per hr., rising occasionally to 50,000 B.Th.U. In marine practice where space is of such value, every effort is being

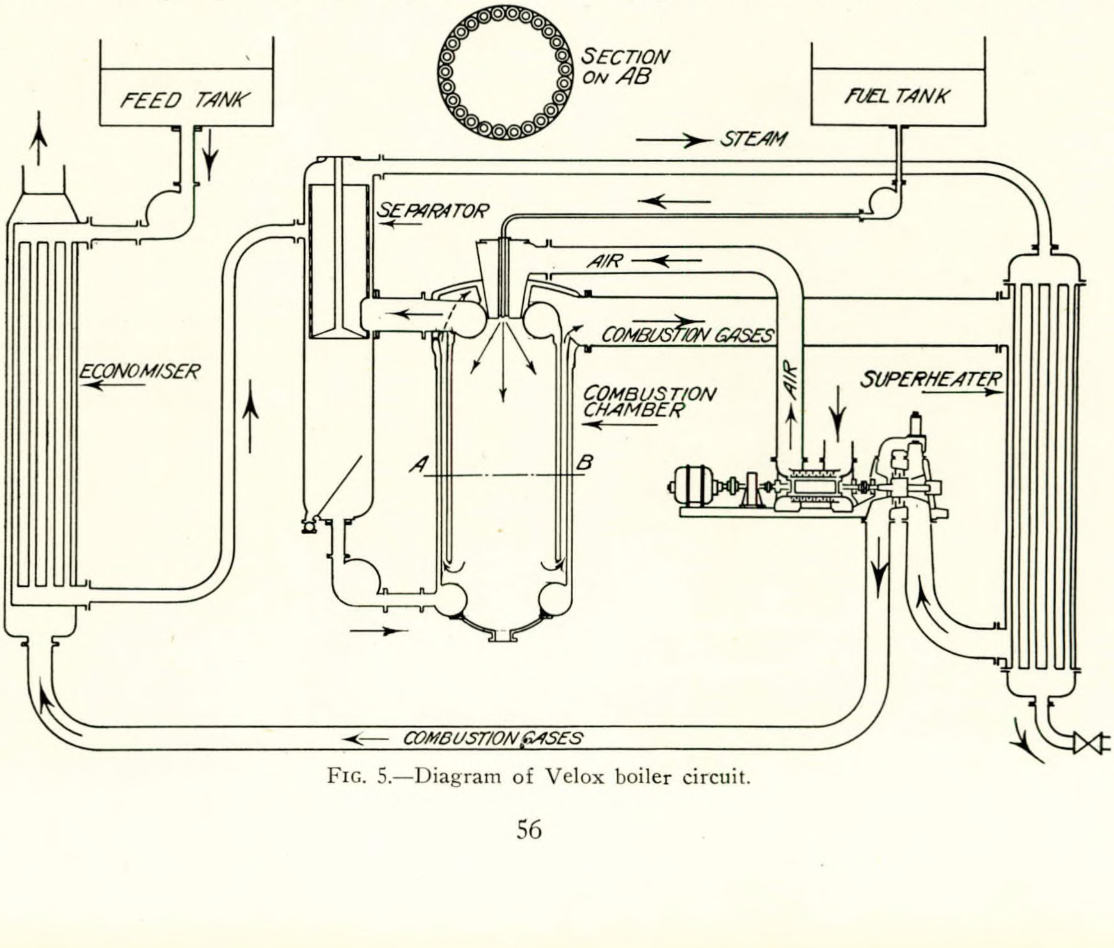

Fig. 5.—Diagram of Velox boiler circuit.

made with the new boiler designs to increase this heat liberation rate, and it will be noted that most of the boilers under review claim very high performance figures under this heading. The practice of high pressure combustion in the Velox boiler may be compared with supercharging in the Diesel engine, where the much increased mean effective pressure of the latter corresponds to the greater intensity of combustion in the former.

The principle of the Velox boiler may be gathered from the diagrammatic sketch shown in Fig. 5. The walls of the combustion chamber are completely surrounded by vertical water tubes, inside of which are three or more small tubes forming a passage for the gases. The products of combustion on leaving the boiler pass to the bottom of the combustion chamber, and then flow upwards through the small internal tubes into a collecting chamber, and from there pass to the superheater.

Dealing first with the water circuit it will be noticed that the feed pump delivery is through the economiser, and thence to the suction of a circulating pump. The duty of this pump is similar to that of the La Mont boiler. It forces through the evaporator tubes in the combustion chamber a quantity of water much in excess of that supplied by the feed pump. This water receives through the walls of the tubes both the radiant heat from the furnace and the convection heat delivered by the hot gases as they rush upwards through the small internal flue pipes. Due to the positive action of the circulating pump and the large quantity of water it delivers, a rapidly moving water-steam mixture passes upward through the evaporator tubes, which are capable of absorbing all the heat that is passed into them from the high temperature radiant flames and the high velocity gases. The mixture of water and steam enters the separator, and here the steam leaves the water and passes to the superheater. The water falls to the bottom of the separator from where, together with the delivery of the feed pump, it is taken by the circulating pump and discharged again through the evaporator tubes.

The fuel air mixture enters at the top of the combustion chamber in which the pressure is maintained at from 20 to 25lb. per sq. in. As previously mentioned the gases, after giving up their heat to the evaporator tubes, pass through the superheater, by which time their temperature will be about 900° F. and their pressure will have fallen by about 5lb. per sq. in. Under these conditions the gas is led to a turbine attached to an air compressor. The compressor draws in the air required for combustion, raises its pressure and delivers it to the combustion chamber at about 25lb. per sq. in. The work of driving the compressor is performed by the combustion gases, which have both their temperature and pressure lowered in the process. On leaving the turbine the gases pass through the economiser, where they give up heat to the feed water, and are then discharged to the atmosphere. It is necessary, however, to indicate that in the modern Velox boiler the superheater is not a separate unit as shown in Fig. 5, but that the superheater elements are placed inside the upper part of the evaporator tubes.

Attention should be drawn to the extraordinary heights to which the high gas speed principle has been carried in this boiler. When advocating the use of high gas speeds in 1910, Nicolson* suggested that the then usual speeds of 10 to 30ft. per second, with heat transmission ranging from 2,000 to 8,000 B.Th.U. per sq. ft. per hr., might some day be raised to 250ft. per sec. with heat transmission rates up to 50,000 B.Th.U. per sq. ft. per hr. In the Velox boiler, gas speeds up to 600ft. per sec. are in common use with heat transmission rates in the evaporator tubes of 100,000 B.Th.U. per sq. ft. per hr. The temperature conditions in the evaporator tubes will be represented approximately by Fig. 1 (*a*). The greater the heat transmission rate the greater will be the difference between θ_1 and θ_2, with, of course, resulting increase of stress due to the greater temperature drop. Incidentally, with the greater rate of heat transmission, θ_2 will also rise to some extent if t (the water temperature) remains constant. Even under the high heat transmission rates just mentioned there is a large margin of safety in the tube stresses, and it will be recognized that overheating the tube metal during normal steaming operations is impossible. It will also be noted that the question of high rate of heat release has been boldly attacked in this design of boiler by the use of combustion under pressure. The figures quoted by the makers in this connection are extraordinarily high, rising from 500,000 B.Th.U. per cub. ft. per hr. in merchant vessels to 1,000,000 B.Th.U. in naval vessels. With such high rates of heat liberation and heat transmission both the volume and the weight of the boiler proper can be brought very low per unit of evaporation, but consideration will have to be given to the space required for and the weight of the circulating pump and the blower.

A special feature of this boiler is the rapidity with which it can be brought into operation, and claims are made that it is possible to start from cold and be under full load within 10 minutes. The writer can support this statement, as he has had the opportunity to see an example of this boiler in operation and to note the ease with which it responded to rapid changes of load. At present there is only one marine Velox boiler in operation at sea, and this is in the service of a Continental navy. It has an evaporation capacity of 33,000lb. per hr., and generates steam at 230lb. per sq. in. and 570° F. An interesting addition is being made to the s.s. "Athos II", a vessel belonging to the Messageries Maritime. This vessel had seven oil-

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* "Boiler Economics and the Use of High Gas Speeds". J. T. Nicolson. Proc. Institution of Engineers and Shipbuilders in Scotland, 1910.

fired Scotch boilers, each capable of producing 15,400lb. of steam per hr. at 215lb. per sq. in. and 540° F. One of these boilers has been replaced by a Velox boiler which, although occupying less space than the unit it replaces, will be capable of evaporating 76,000lb. of steam per hr. at a pressure of 685lb. per sq. in. and 840° F. This high pressure steam is used in a new two cylinder turbine with separate condenser. The new power unit is coupled to the original turbines and shafting, thus almost doubling the output and raising the speed from 16 to 20 knots. The first vessel to be equipped entirely with Velox boilers is a small Baltic passenger vessel at present under construction. Two Velox units will be installed, each capable of evaporating 17,600lb. per hr. It is estimated that by using these boilers rather than those of the standard type the passenger accommodation will be increased by 12 per cent.

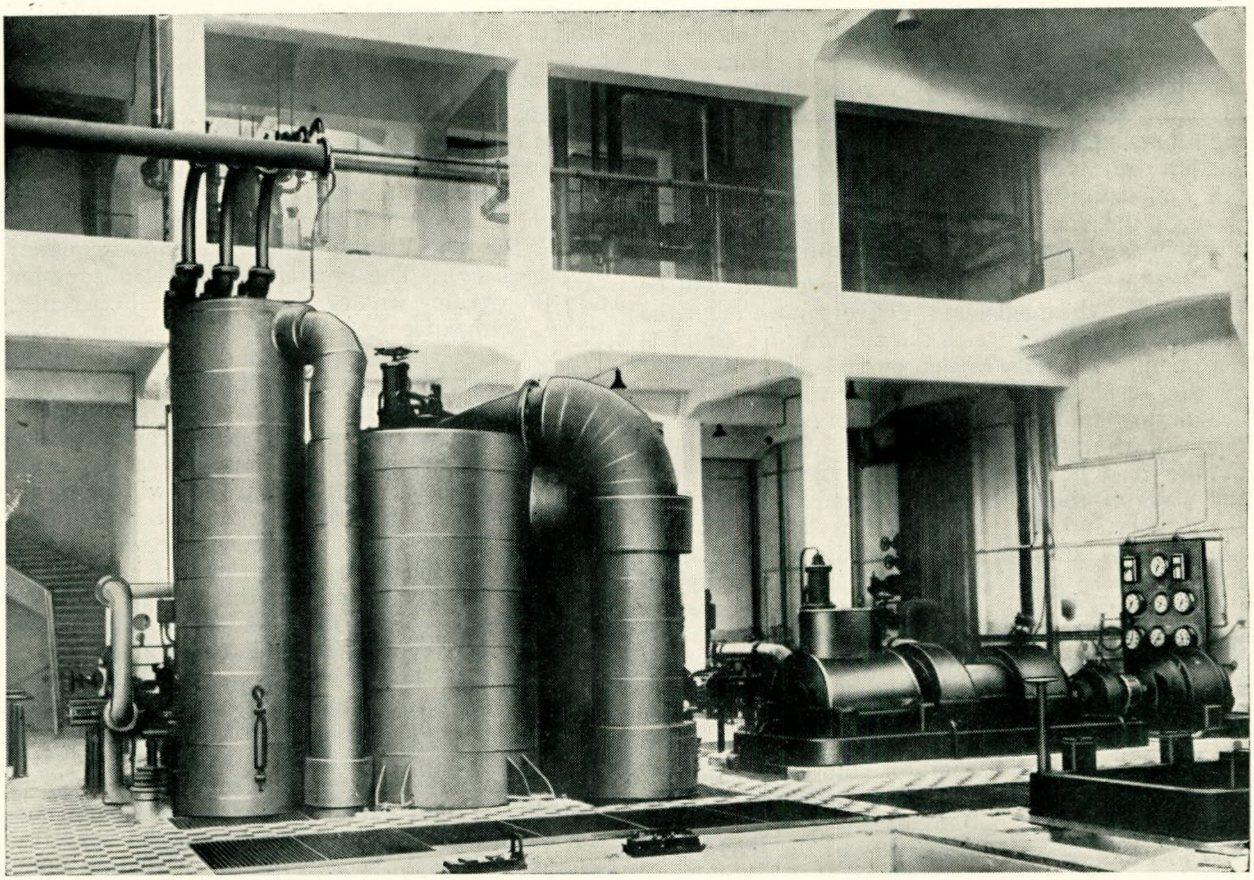

FIG. 6.—Complete Velox steam generator installation. Capacity : 76,000lb. of steam per hr. at 380lb./sq. in. g. and 950° F.

It has not been possible to obtain trial results from vessels at sea, but it is claimed by the makers that there is no material difference between a standard land Velox boiler and one suitable for merchant ships. The following test results obtained from an oil-fired unit installed at Wellington, New Zealand may therefore be of interest :—

Working pressure. lb. per sq. in. abs. ...	247
Steam generated. lb. per hr.	94,860
Feed temperature. deg. F.	122
Steam temperature deg. F.	630
Uptake temperature. deg. F.	221
Efficiency (on lower C. V.) per cent. ...	95·6

It is shown by the test results that there is little change in efficiency between one-third and full load.

Loeffler Boiler.

The outstanding feature of this boiler is the boldness of its design, and the manner in which a real appreciation of the principles of heat transmission has been applied to a difficult engineering problem. It is generally known that in the great majority of boilers, the furnace gases have had an appreciable drop in temperature before they come into contact with the superheater tubes. In the Loeffler boiler the heat from the furnace gases at their maximum temperature is received by tubes containing steam alone, and not a mixture of water and steam as is the usual practice. In the earlier part of this paper it was indicated that with high heat transmission rates, there was some difficulty in maintaining moderate tube temperatures, even with a water-steam mixture inside. With superheated steam circulation the difficulty is greatly increased and as will be seen by reference to the Reynolds equation high values of $\rho_2 v_2$ or of $\frac{w_2}{a_2}$ are necessary if θ_2, the temperature at the inside of the tube, is to remain at a safe level. But high values of $\frac{w_2}{a_2}$ are associated with high rates of heat transmission, H, and consequently with high values of $(\theta_1 - \theta_2)$. Thus the stresses in the tube due to the difference of temperature between the outer and inner walls may become serious.

In the diagrammatic sketch shown in Fig. 7 it will be noted that the radiant heat superheater tubes line the walls of the combustion chamber, and that the combustion products after leaving the chamber give up their heat to the convection superheater, economiser, and air-preheater in turn. The steam is produced in the lower drum, which is well away from the furnace gases, and is then drawn through a circulating pump which raises its pressure by an amount necessary to overcome the frictional resistance of the tubes, and forces this high-pressure steam at a high velocity through the radiant and convection superheaters. At the junction "J", shown in the sketch, part of the steam goes off to the turbine, and the remainder passes into the evaporator drum. Here it mingles with the feed water, which has passed through the economiser and, by giving up its superheat, evaporates an amount of water equivalent to that required by the power plant. Thus it will be seen that the circulating pump performs a duty similar to that of the pumps in the La Mont and Velox boilers. The weight of steam forced through the superheater is much greater than that required to pass to the turbine, and thus it is possible to obtain very high values of $\frac{w_2}{a_2}$.

From figures published in "Engineering" there have been calculated the approximate values of the amount of steam forced through the superheater tubes, and that passing to the turbine. In this example the steam required for power purposes amounts to 68 tons per hr., and this leaves the boiler at a pressure of 1,850lb. per sq in. and a temperature of 930° F. The feed water enters the evaporator drum at 500° F. and at the rate of 68 tons per hr. In order to evaporate one pound of feed 2·23lb. of steam must also pass into the evaporator drum. Consequently the steam forced through the superheater tubes by the circulating pump will amount to 220 tons per hr. From estimates of the total area for flow it is found that $\frac{w_2}{a_2}$ has the very high value of 236lb. per sq. ft. of flow area per sec. The mean velocity of the steam in this section will approximate to 60ft. per sec. and the pressure drop in forcing the steam through the radiant superheater tubes at this velocity will be at least 30lb. per sq. in.

From figures supplied by the makers it is found that at one section of the superheater the heat transmission amounts to 92,000 B.Th.U. per sq. ft. per hr., and assuming a value of the co-efficient K as 4 the approximate drop of temperature through the tube wall (¼in. thick) will be 100° F. The approximate temperature conditions in this part of the superheater are shown in Fig. 1 (*b*) where the outside temperature of the tube is in the region of 1,000° F. The total stress on the inside of the tube due to pressure and temperature effects, and calculated according to the usual elastic theory will be about 10 tons per sq. in., a value which under these temperature conditions seems rather high. Against this must be set the remarks of Dr. R. W. Bailey* who, in discussing stress conditions similar to this, states: "Heat transmission through the walls of a tube in giving rise to a temperature

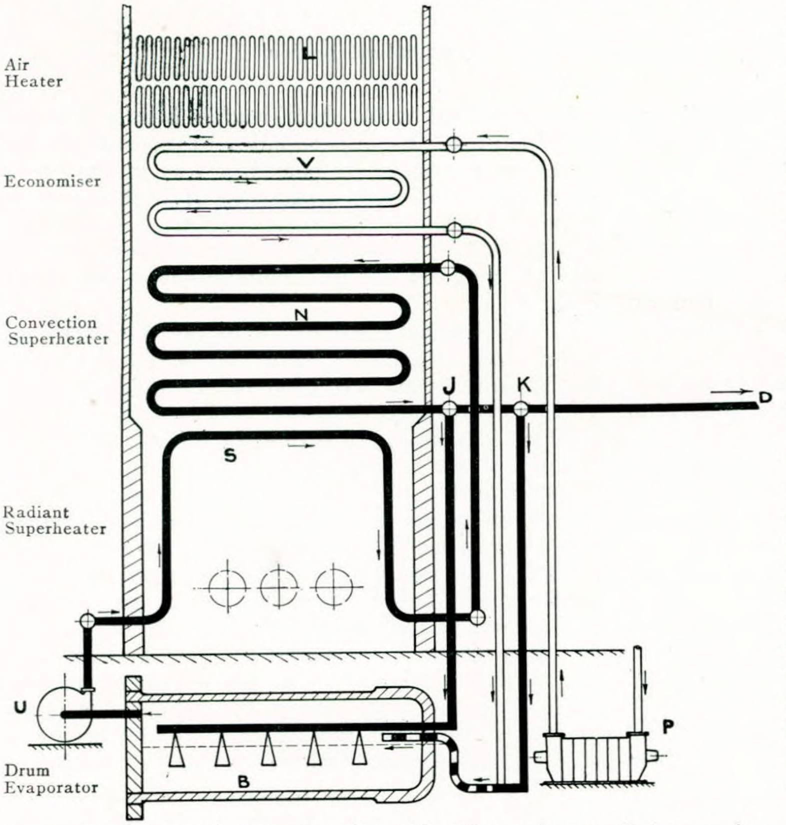

FIG. 7.—Diagrammatic representation of Loeffler system applied to marine boilers.

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*Utilization of Creep Test Data in Engineering Design. R. W. Bailey, Proc. I. Mech. E., 1935.

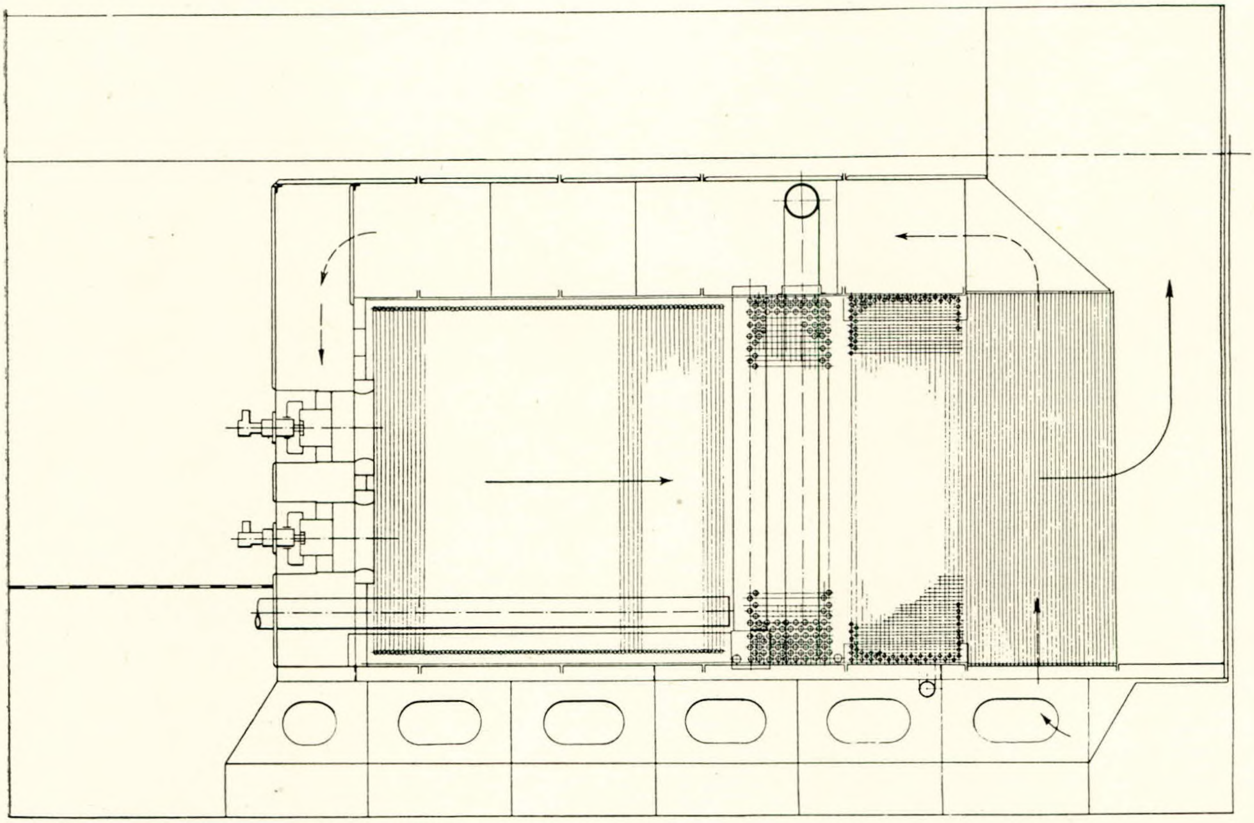

FIG. 8.—Loeffler boiler for torpedo boat. Longitudinal section.

gradient, produces stresses initially in accordance with elastic theory. It follows from the results already noted for cylindrical parts that creep would set in immediately, and would operate continually to reduce these stresses to small and negligible magnitude". It would be interesting to have during the discussion some remarks upon this stress relief. Quite recently the writer had an opportunity of inspecting a number of Loeffler boilers under working conditions, and of seeing others under construction. He was much impressed by the excellence of machinery and workmanship, and by the technical ability of the staff. Every opportunity was given him to make full investigations of the performance of the boilers, and his general impression was that whatever difficulties may arise, the manufacturers are capable of coping with them.

It will be recognized that the Loeffler boiler is essentially for the production of high pressure and high temperature steam. In order to keep the steam circulating pump within reasonable dimensions the pressures must be high, and consequently it will be found that these are in the neighbourhood of 1,800 to 1,900lb. per sq. in., and that the outlet temperature of the steam is about 900° F.

The installation of the Loeffler boiler in the s.s. "Conte Rosso" is now well known, and has been fully described by Mr. McEwen* in his paper before this Institute. Figures supplied to me indicate that in a recent voyage its efficiency was in the region of 90 per cent., with a pressure of 1,900lb. per sq. in., and a steam temperature of 896° F. For these trial conditions the feed water temperature was 248° F. and the flue gas temperature at the uptake 302° F.

The detailed construction of the "Conte Rosso" boiler may be studied from Mr. McEwen's paper, but an interesting variation of the design suitable for a torpedo boat destroyer will be seen in Fig. 8. In Fig. 9 is shown a projected scheme, where the whole of the power developed is supplied by a Loeffler boiler. The installation is designed for a merchant vessel of 6,000 s.h.p. with electrically driven auxiliaries. After expanding in the h.p. turbines, the steam is reheated by a portion of the boiler steam before it passes to the l.p. turbines, and thence to the main condenser. A low pressure boiler is provided for port purposes and for starting the Loeffler boiler. The connection of its steam main with the circuit after the reheater is clearly shown. The other details of auxiliary drives are also indicated, and need no further description.

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*The Loeffler Boiler Installation in the s.s. "Conte Rosso". S. McEwen. Institute of Marine Engineers, March, 1937.

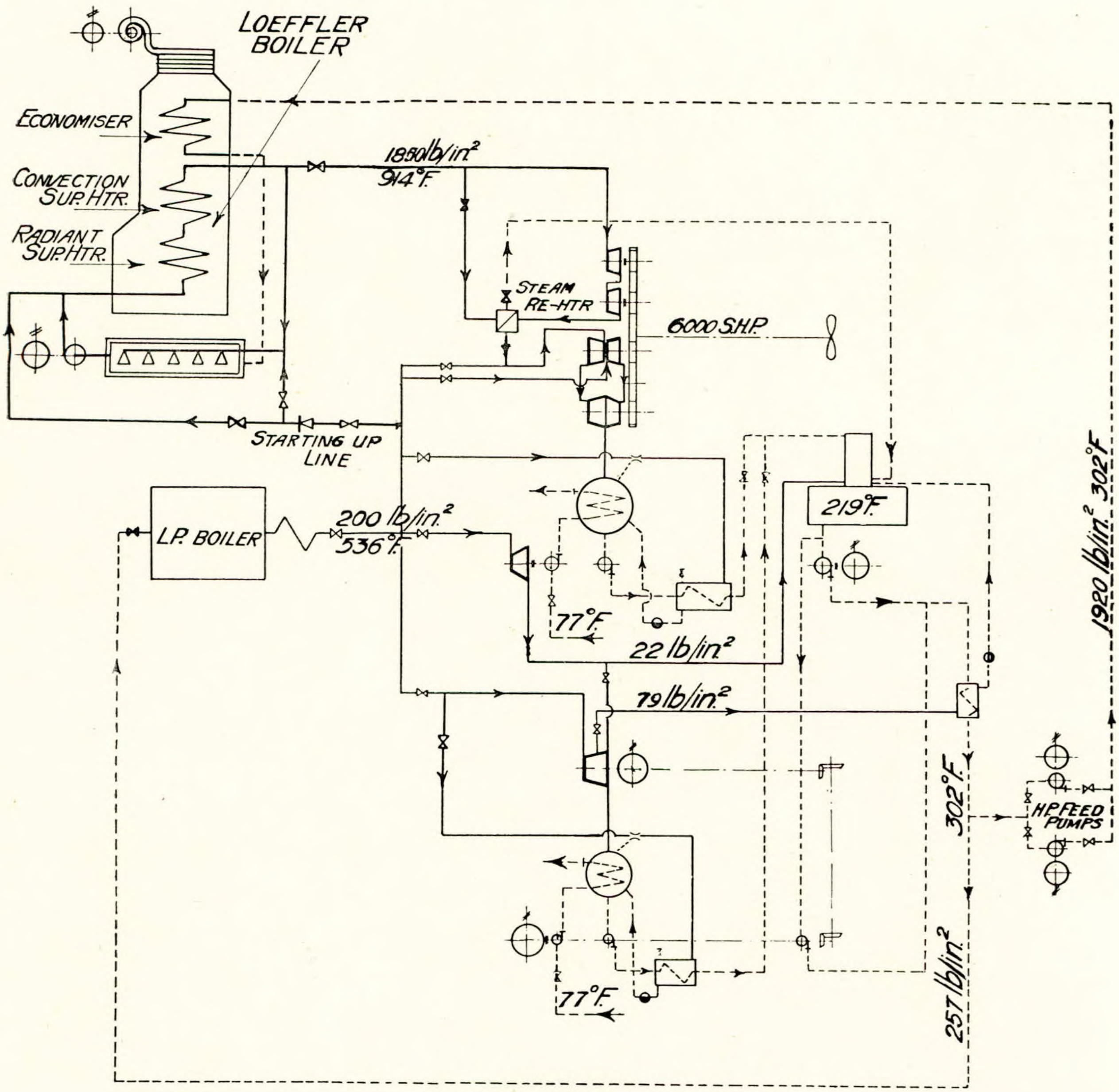

FIG. 9.—Arrangement of Loeffler boiler with electric drive.

Benson Boiler.

The Benson boiler differs from those already described in having no steam drum, and in consisting entirely of small tubes with their associated headers. The nature of the circuit can be seen in the diagrammatic sketch Fig. 10, from which it is evident that here again we have a boiler working with forced and controlled water circulation. Originally designed for generating steam at the critical pressure (3,200lb. per sq. in.) the first Benson boiler installed in the s.s. "Uckermark" of the Hamburg-America Line has been in continuous service since 1930. From experience gained by the operation of this boiler further units have been designed and made by Messrs. Blohm and Voss, and installed in the s.s. "Potsdam" of the North German Lloyd, and the s.s. "Pretoria" and the s.s. "Windhuk" of the German Africa Line.

Under present day conditions the critical pressure operations are no longer considered necessary, and the latest examples have a working pressure of 1,154lb. per sq. in. The tubes are only 1in. diameter, $\frac{5}{32}$in. thick, and those in the combustion chamber of a 0·4 per cent. molybdenum steel. In the steamers "Pretoria" and "Windhuk" the boiler room contains two Benson and one auxiliary water-tube boilers, along with all auxiliaries. In the design special care is taken so to proportion the

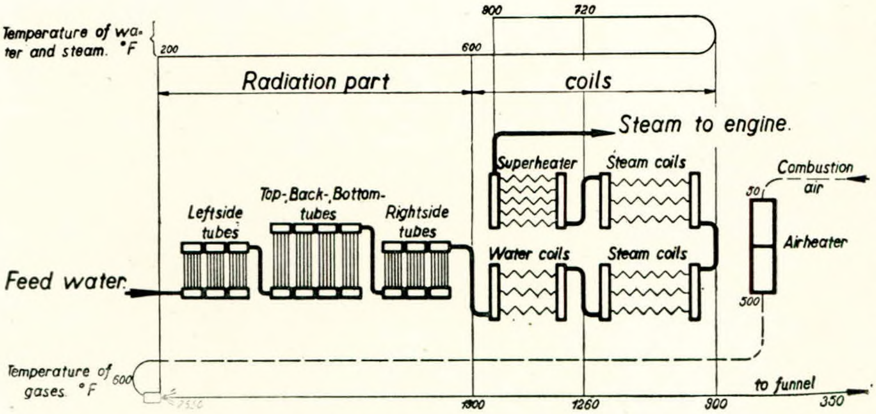

FIG. 10.—Benson boiler. Diagram showing temperature and flow of feedwater and steam, temperature and flow of air and combustion gases.

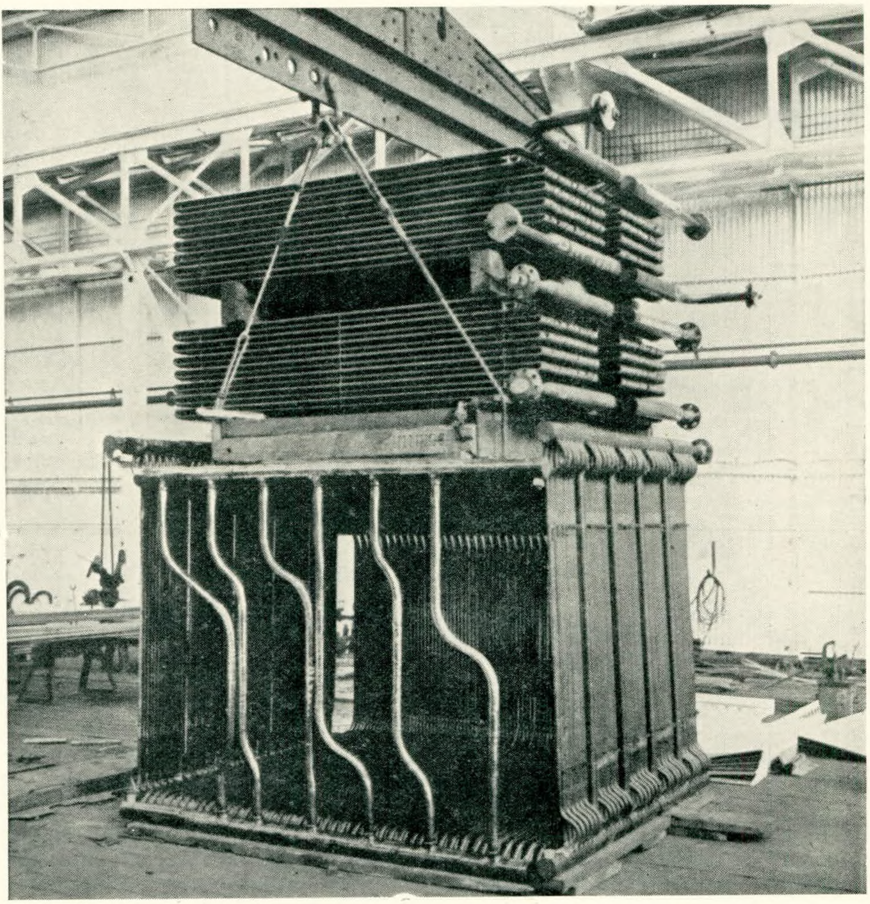

FIG. 11.—Benson boiler as erected in the shop.

heating surface that those tubes containing only saturated steam are outside the radiation heat section, so that the majority of any deposit that may be made on the inner tube surface will be away from the hottest gases, thus reducing the danger of overheating.

Arising from earlier experiences simplification has been effected by the uniform sub-division of all tube nests forming the individual heating surfaces, and by making the nests and the tubes throughout of uniform dimensions. The resistance to fluid flow has also been appreciably diminished by increasing the number of tubes connected in parallel. This has brought about a great reduction in the power required to drive the feed pumps.

Under normal load conditions each boiler produces 61,600lb. of steam per hr. at a pressure of 1,154lb. per sq. in., and a temperature of 842° F. It is stated that this output can easily be increased to 88,000lb. of steam per hr., so that with one boiler out of action, the vessel could continue her voyage with over 60 per cent. of the normal power available. From records taken during sea service it is estimated that under normal loads the efficiency of the boiler is 91 per cent., and the oil consumption for main engines and auxiliaries is 0·617lb. per s.h.p./hr.

Sulzer Monotube Boiler.

In principle there is a close resemblance between the Sulzer and the Benson boiler, although they differ in practical details. Both are without steam drums, and in both there is a continuous forced circulation through long tube lengths of small diameter. In diagrammatic form the principle of the boiler is shown in Fig. 12, where the feed water inlet at the top and the superheated steam outlet, after the long journey through the four nests of tubes, are indicated. According to Mr. Calderwood the tube length is of the order of 30,000 times the internal diameter of the tube, which means that with an inch diameter tube the water will have a journey of about half a mile before it issues as superheated steam. Obviously each boiler does not necessarily consist of only one tube, and according to the required output different numbers of tubes can be arranged in parallel.

From the diagram it will be seen that, unlike the Benson boiler, the superheater tubes are arranged round the walls of the combustion chamber, and subjected consequently to the radiant heat reception. The conditions are similar therefore to those in the Loeffler boiler, and high values of $\frac{w_2}{a_2}$ will be necessary to prevent overheating of the tubes.

As a protection against scale deposits in the superheater tubes provision is made to treat, either continuously or periodically during service, the water in the generator. A separator is arranged at the end of the evaporator section of the tube system. Through this the saturated steam and the remaining water are passed, and the dry saturated steam separates out practically free from impurities. The water, which contains the greater part of the salts originally in the feed, falls to the bottom of the separator and is automatically released. The concentrated salt solution thus discharged is automatically replenished by pure feed water, and the deficiency in the feed reservoir made up by distilled or chemically treated water.

The only Sulzer marine Monotube boiler was installed in the s.s. "Kertosono" in 1936. It was oil-fired with an output of 44,000lb. of steam per hr. at a pressure of about 850lb. per sq. in., and a temperature of 715° F. Due to a collision the vessel has been laid up, and its service up to now amounts only to 3,500 working hours. Considerable experience has been gained, however, with numerous boilers in land service, and it is of interest to note that several installations of large plants have been ordered for factories in this country.

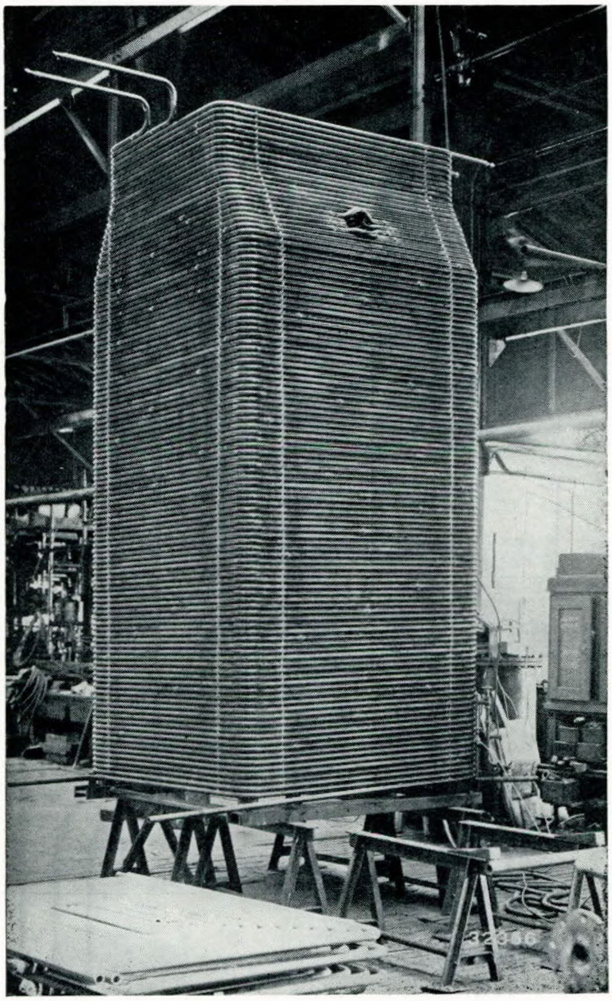

FIG. 13 (above).—Combustion chamber for Sulzer "Monotube" marine boiler; 23,000lb./hr. steaming rate.

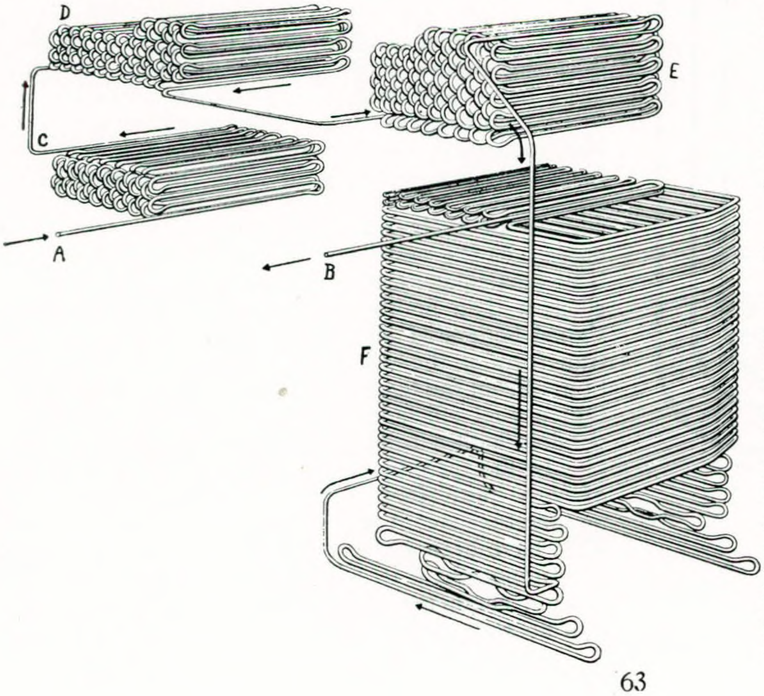

FIG. 12 (left).—Tube system of Sulzer "Monotube" steam generator: (A) feed water inlet; (B) superheated steam outlet; (C, D, E) tube bundles which can be arranged to suit space available; (F) tube lining of combustion chamber.

Schmidt-Hartmann Boiler.

The Schmidt-Hartmann boiler consists, as will be seen in Fig. 14, of a primary and secondary system. The former is filled with distilled water which, except for leakages, remains unchanged. The steam generated in this boiler passes through coils situated in the secondary drum, and by giving up its latent heat, evaporates the working steam at a somewhat lower pressure. This steam then passes through superheaters placed in the path of the flue gases from the primary boiler, and is then conducted to the power plant. The circulation in the primary boiler is continuous and automatic, as will be seen from the steam and water circuits indicated in Fig. 14. The main reason for this design is that it does away with the necessity for special treatment of the feed water, and it is claimed that even for high pressures no more precautions need be taken in this system than are required for the ordinary Scotch boilers.

It is stated that there are now 48 boilers of the Schmidt-Hartmann type in service on land, and that a marine example was put into operation on the s.s. "Altair" of Bremen in October, 1937. In this installation there are two separate boilers, each with an output of 9,260lb. per hr. The pressure of the working steam (secondary boiler) is 740lb. per sq. in., and this is superheated to 900° F. The maximum pressure for the primary boiler is 1,500lb. per sq. in., but it is designed to perform its normal duties at 1,200lb. per sq. in. The margin is intended to be used as a reserve should there be any scale deposits on the coils in the secondary drum. Oil firing is used, and both superheater and air preheater are installed. There is no economiser, but the feed is heated to about 265° F. before it enters the secondary drum. Shop tests before installation on board indicated an efficiency of 87 per cent., and it is reported that up to the present time the behaviour of the plant in sea service has been satisfactory. A sectional view of one of the boilers is shown in Fig. 15.

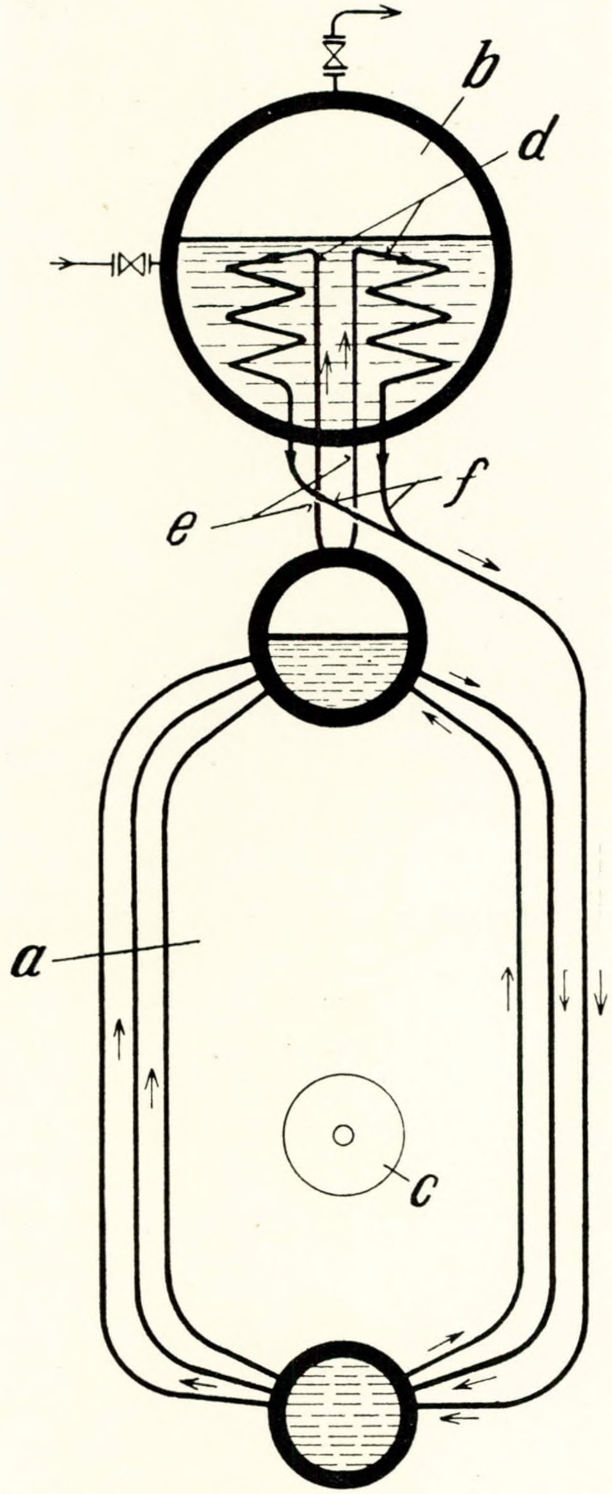

FIG. 14.—Diagram of Schmidt-Hartmann marine boiler: (*a*) Primary boiler; (*b*) secondary boiler; (*c*) oil burner; (*d*) evaporation element; (*e*) superheated steam outlet; (*f*) condensed steam return pipes.

General Considerations.

To those whose attention has been confined to the standard Scotch boiler the steam and water circuits of some of these modern boilers may appear almost fantastic. Yet it must be remembered that of all the types described there are many examples in practice, and that both on land and at sea, much experience in running service has been gained.

One of the first questions arising is that associated with fuel economy, and it might be asked—does this review show that any one type of boiler has a better efficiency than the other? The answer to that question is that it does not. It will have been observed that whereas some of the boilers described are fitted with air preheaters and economisers, others are not, and thus a true comparison of their relative performances cannot be made. At the same time it might be said that there is no particular reason why one type should be more efficient than another, and that, in fact, well designed boilers of all classes are equally capable of transforming the heat of the fuel into steam production. From the figures supplied it might be assumed that a fuel efficiency round about 90 per cent. is possible with a fully equipped plant.

In the introduction to this paper the necessity of very pure feed water for high pressure and temperature steam production was indicated, and it must have been apparent throughout the discussion how important it is, with the high rates of heat reception characteristic of the new styles of boiler, that no scale, with its great resistance to heat transmission, should be allowed to form on the inner tube surface. In this connection it would appear that the Schmidt-Hartmann boiler has the greatest margin of safety, and that the Loeffler boiler with its indirect method of evaporation should also be in a fairly happy position. This difficulty of deposits not only applies to the boiler, but may also give trouble in the turbine. It has been found in quite a number of cases that the sodium salts used in the feed treatment volatilize in the superheater, and are deposited on the turbine blading, thus cutting down the power output. Some designs of steam washer are stated to get over this difficulty.

The difficulties associated with steam drums under high pressure were briefly touched upon, and it will have been evident that such difficulties have been appreciated by the designers of most of the new plants. The Loeffler steam drum is removed altogether from the region of the flue gases, and has therefore no trouble due to external heating. Its symmetrical shape and its freedom from holes in the circumference also lead to an absence of those bending moments which it was pointed out may produce such heavy stresses. The Velox boiler with its steam separating drum is in a similar happy position, but attention will be required in the design and construction of the steam and water collectors at the top and bottom of the combustion chamber. The Benson and Sulzer boilers solve the problem by omitting the drum altogether, and incidentally save appreciably in constructional cost and weight. Here then the old question associated with water and steam reserve must arise. With the displacement of the Scotch boiler by the water-tube boiler, this problem was greatly to the fore, and it seems that there is now another chance of bringing it up in its association with the drumless boiler. Obviously close and efficient regulation is a necessity; most of the boilers described have their own regulating systems, but space has not permitted their being described in this paper. It is hoped, however, that some experiences during service will be given during the discussion, together with some information of how they would operate in difficult and unexpected conditions.

The other point upon which attention will be

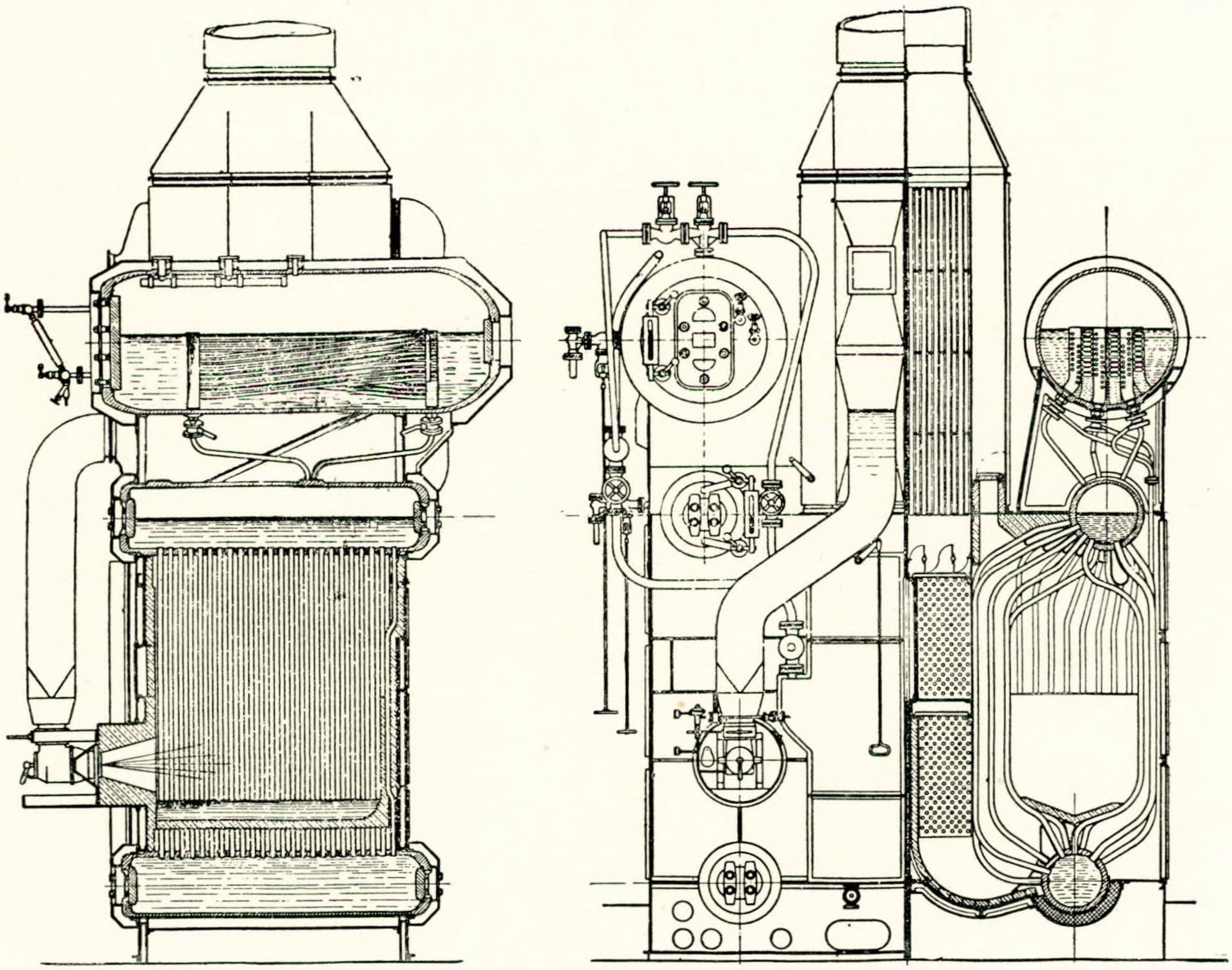

FIG. 15.—Sectional view of Schmidt-Hartmann boiler for s.s. "Altair".

concentrated is that of weight and volume per unit of steam production. As previously stated the differences in equipment of the boilers described have made the comparison up to now difficult if not impossible, but it is hoped that from the discussion information may become available which will clear up the situation.

Finally it might be asked, although this does not come really within the scope of the paper—Why do we want these very high pressures, and is there any pressure at which we should expect maximum economy?

I have to thank my colleague Dr. O. Sneeden for assistance in the preparation of some of the diagrams. My thanks are also due to the firms which provided the drawings and information necessary for the descriptions of the different boilers.

Discussion.

Dr. S. F. Dorey (Vice-President), opening the discussion, congratulated the author and expressed the view that Professor Mellanby's reputation and the subject with which he had dealt in his paper were responsible for the Lecture Hall being filled to capacity. The present-day tendency was towards increased pressure. The author had said that he did not see the advantage of increased pressure, and perhaps some engineers present could give the answer to that. The tendency to increase pressures in marine work was not great, the general aim seeming to be to keep to a moderate pressure of the order of 500 to 700lb. with a temperature varying from 750° to 900° F.

The author mentioned that as service results were to a large extent lacking, the title of his paper was not quite correct, but he (the speaker) had no doubt that the representatives of the manufacturers of the various boilers mentioned in the paper who were present would be able to give a certain amount of information.

The author also stated that there was a number of these types of boilers in use, but from a marine point of view this also was not quite correct, as their use on ships was only in an experimental stage. Most high-pressure experience had been obtained with the Benson boiler, which started at a pressure of 3,200lb., since reduced to 1,800lb., and was now running at 1,150lb. This showed the tendency to keep down pressures and use higher superheat.

It was not his (the speaker's) duty to criticize these boilers on the point of comparative efficiency and first cost, but to consider them from the strength point of view, facilities for inspection and overhaul, and behaviour in service. Behaviour in service involved reliability, and marine engineers must consider whether they would be prepared to fit one of these high-pressure boilers in a one-boilered ship. They had sufficient experience to put a Scotch boiler in a one-boilered ship, but these high-pressure boilers were a different matter. On land it was more simple, as a trained staff and facilities were available to deal with any trouble that might arise. It was different in marine work and, frankly, these boilers were in an experimental stage in that sphere. Even in land work all these types of boilers had suffered with burst tubes, causing unpleasant trouble and delay. Tube bursts were due to overheating and local heat storage sometimes caused by darting flames and unsuitable flue gas paths, but mainly by impurities and deposits in feed water; failure in tube fabrication, internal and external surface defects, ridges, scores, etc., were other causes.

Under marine conditions these troubles would be intensified due to difficulties with the feed water which might have to be taken in any part of the world. The manufacturers were quite able to cope with these difficulties if they were on the spot, but as they could not get to a ship on the high seas in any part of the world it was evident that the use of these boilers in marine work was a very different proposition from their use on land.

Two fundamental points should therefore be stressed, viz. :—(1) feed-water treatment to be still further improved although distilled water was used, and (2) the manufacture of the tubes made more perfect, tubes to be pickled before final examination and special care in fitting to boiler drums and headers. Even now it was found in land work that it was necessary to give the most careful attention to the feed water. The water was now treated with tri-sodium phosphate to reduce its hardness and thus prevent scale deposition, but too much sodium phosphate meant trouble with the turbine due to a deposit on the blades. It was possible by blowing down the boilers to keep the quantity of sodium phosphate low, i.e., about 5-10 milligrammes per litre (0·2 to 0·4 oz. per ton). Soluble deposits could be removed by washing with wet steam, but a hard deposit such as silica meant boiling out the turbine. A further point in connection with feed water was the employment of de-gassing appliances, new evaporators with h.p. and l.p. stages, and continuous supervision of feed water by keeping the right "natron" figure (in the "Uckermark" this was 200). Trouble had also been experienced through excessive use of sodium hydroxide in the water causing excessive priming and scale formation in the superheater tubes.

It would be realized that the marine engineer must give more attention to all these problems which would arise at sea just as they had arisen on land.

With regard to tube material, ordinary mild steel had given ample satisfaction for the pressures and temperatures used in average marine work. The Benson boiler had tubes of 0·3 to 0·5 molybdenum steel and that had given satisfactory results. There was a tendency to utilize this particular material for all these high-pressure boilers.

The internal corrosion of tubes due to decomposition of steam for the higher pressures did not appear to be present. So far as the oxygen content was concerned, if care was taken corrosion could be prevented so long as the circulation was good, but for reliable service it would appear that the oxygen content should not be greater than ·05 milligrammes per litre (·002 oz. per ton).

Mention had been made of creep or relaxation of stress due to creep. So far as the boiler evaporator tubes were concerned, these were undoubtedly not subject to creep. On the other hand, superheater tubes were subject to creep and relief of stress took place due to plastic flow.

Another important point was that all these boilers were being operated on land under expert supervision and it was therefore necessary that anyone wishing to employ them for marine purposes should ensure that a specially-trained staff was available. Not only had the working of the boilers themselves to be considered, but also the essential auxiliaries.

With regard to scale, they had been told twice in the paper that no overheating of the tubes would take place. It would be almost impossible to clean the tubes of some of the boilers. It was only the maintenance of very rapid circulation which would help to prevent the formation of scale. This was, however, linked up with feed-water treatment to which he had already referred.

Another point of prime importance to the marine engineer was the facilities for overhaul and inspection.

With regard to breakdowns, the Velox boiler had a number of elements around it. With this type of boiler steam could be raised in a few minutes and should an element burst steam could be let down very quickly and the element taken out and either replaced or the holes plugged. A more expert supervision of the boiler plant would, however, be necessary. A more up-to-date illustration of the Monotube boiler would have shown that it was divided up into a number of elements, and if anything happened to the tubes it was necessary to cut out the entire element. The Schmidt boiler did not present any difficulties beyond those already familiar in connection with ordinary water-tube boilers. The Loeffler and La Mont types required special attention in regard to the circulating pumps. Regarding welded joints, experience had shown that these were satisfactory.

He had been fortunate in seeing some of these boilers in land installations on the Continent, some of which had been in service for a number of years, and generally speaking they were all giving satisfactory service. Split tubes had not given undue concern as might be imagined.

He had had little opportunity of obtaining experience with La Mont boilers working at high pressures, but in the case of a large number of donkey boilers of 250lb. pressure satisfactory results had been obtained.

In conclusion, he hoped that the manufacturers would give details of their experience on the land side, if it was not possible to do so on the marine.

Mr. W. Roylands Cooper (Visitor) said that in concluding its review of marine engineering in 1937 "The Engineer" expressed the opinion that information was really needed on the subject of service results with high-pressure boilers, and the suggestion was made that a paper before a leading international institution would be specially welcome. It was therefore with great pleasure that he had learned that Professor Mellanby was going to take this task in hand.

His (the speaker's) contribution to the discussion was related to the Benson boiler with which he had come in contact at sea and on land, and he supplemented Professor Mellanby's paper with some illustrations of recently completed marine type Benson boilers which he had just received from Germany.

Incidentally the first Benson boiler was built and tested at Rugby and a short time ago it was offered to the Science Museum, but as there was no room for it it could not be accepted and unfortunately was, he believed, destroyed. The Benson boiler had been developed by Siemens Schuckert of Berlin for the International Benson Co., and Messrs. Blohm and Voss of Hamburg had under licence from Siemens Schuckert concentrated upon it for marine work. The fact that firms of such international repute had taken it up so enthusiastically showed that there was something in it, and it seemed unfortunate that its development had not been persevered with in this country.

The most interesting marine type Benson boilers were those recently installed in the two liners "Pretoria" and "Windhoek" built and engined by Blohm & Voss for the German African

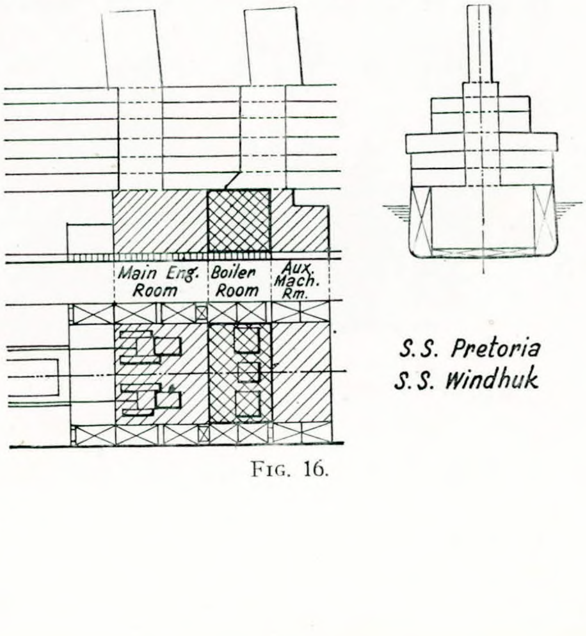

FIG. 16.

Lines. They had a length of 578ft., with a beam of 72ft. and a measurement of 16,662 gross tons. Their propelling machinery was designed for a speed enabling them to cover the distance from Southampton to Cape Town in fifteen days. It comprised a twin-screw arrangement of geared turbines taking steam from two Benson steam generators with a designed working pressure of about 1,200lb. per square inch. A smaller Benson boiler working at about 360lb. was provided for port use. The machinery had a designed output of 14,200 s.h.p. The auxiliary generating sets included two 550kW. turbo-dynamo sets and two 380kW. oil engine-driven sets. Like others of the latest German liners, the propeller shafts ran in roller bearings. The size of the plant was small and the weight less than with a normal design. Fuel consumptions of less than 0·6lb. of oil fuel per shaft horse-power-hour were claimed, and the ships had run very regularly throughout their period of service with increasing overall economy.

The general arrangement of the machinery in the ships was illustrated in Fig. 16, while Fig. 17 showed one of the boilers' casings without the tube nests being prepared for lifting aboard. A general idea of the water and steam circuit would be found in the sectional drawing reproduced in Fig. 18 which also indicated the principal dimensions of the boiler. The accompanying table, Fig. 19, had been prepared to show the development of the marine boiler as typified in recently constructed German liners. A great advantage of the Benson boiler would seem to be the use of small bore tubes and welded constructions without the need of boiler drums, which greatly reduced the time required for building a boiler and its cost. The Benson system was also applicable to wide ranges of pressure, and service results were now available with marine, power station and industrial designs, burning oil and powdered fuel. The actual working experience with these boilers would, if available, be a valuable addition to the present paper.

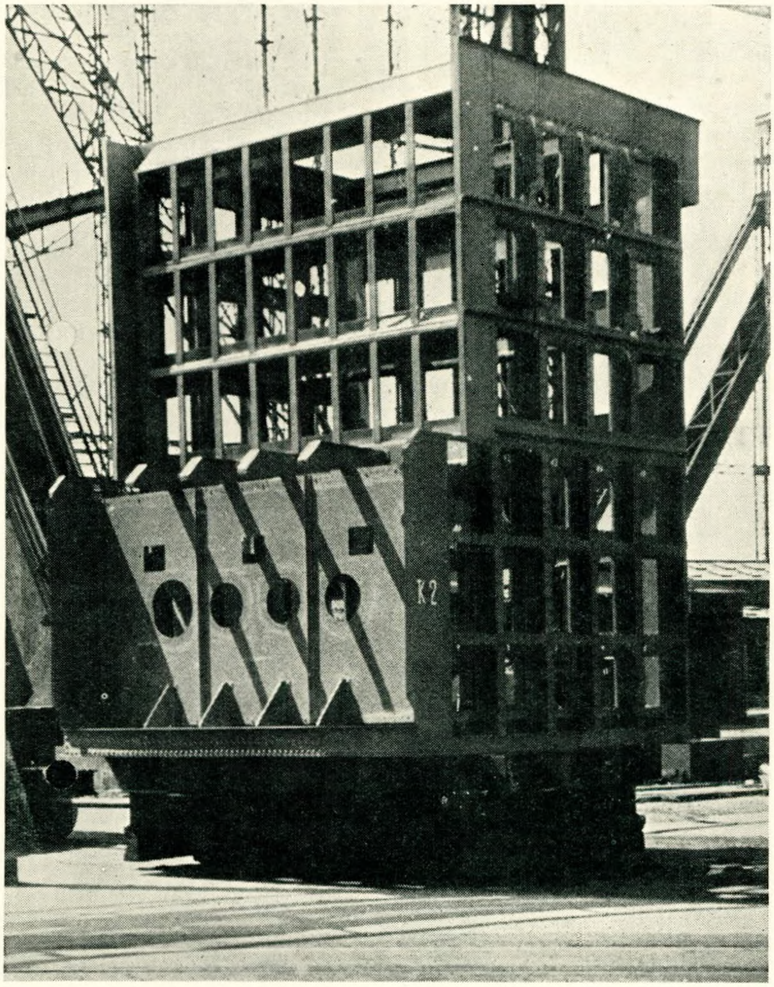

Fig. 17.

Major W. Gregson, M.Sc. (Visitor) stated that he would confine his remarks chiefly to the subject matter of the paper (forced-circulation boilers) rather than to the title (high-pressure boilers) as little was given in the paper on the subject of high-pressure installations.

He had rather unique experience in being associated with a Company which manufactured a very wide range of boiler designs, and which had also had considerable experience in connection with the development of forced-circulation systems. Speaking from the Mercantile Marine point of view, they were still operating natural-circulation water-tube designs at ratings well below figures which could be maintained with absolute safety. Why complicate matters by becoming involved in mechanical circulation which must of necessity mean, by adding a mechanical link to the chain, a lower factor of reliability?

Economy in weight and space was a function of boiler rating, and the well-known and proved types of marine water-tube boiler still had so much in hand—while still keeping within safe operating limits—that it would be time enough to consider forced circulation when the limits of natural circulation were reached.

Good feed conditions were essential as ratings and pressures went up, and this remark applied equally to forced- as to natural-circulation units, as the idea that high water speed over the heating surface avoided

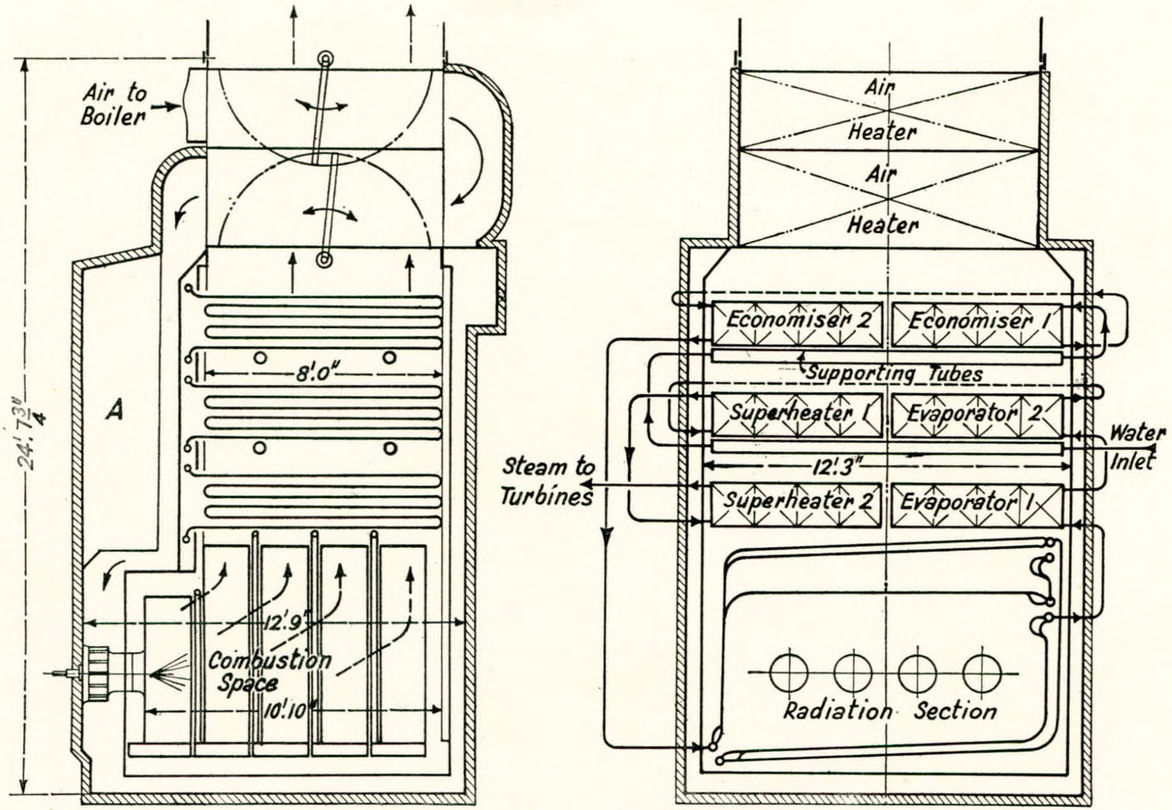

FIG. 18.

Name of Ship	S.S. Hamburg	S.S. Bremen	S.S. Hamburg (Rebuilt)	S.S. Gneisenau	S.S. Potsdam	S.S. Pretoria S.S. Windhuk
Year Constructed	1925	1926	1927	1934	1934	1936
Type of Boiler	Large Cylindrical Boiler	Water Tube Boiler				
		Natural Circulation			Forced Circulation	
Ratio: $\frac{\text{Boiler Weight. T.}}{\text{Steam Output. T/Hr.}}$	9·8	4·9	4·7	2·8	2·1	1·5
Ratio: $\frac{\text{Boiler Area in } M^2}{\text{Steam Output T./Hr.}}$	3·2	1·6	1·5	0·72	0·54	0·4
Ratio: $\frac{\text{Boiler Volume } M^3}{\text{Steam Output T/Hr.}}$	23·5	11·5	11·0	6·1	4·3	3·0

FIG. 19.

scale deposition was not borne out in practice.

On the score of efficiency, all modern marine water-tube installations were about the same, provided suitable arrangements were incorporated in the design to reduce the gas temperature to the lowest practical limits. In the case of certain forced-circulation designs, this was effected by considerable economiser surface, which surely reduced potential *overall cycle efficiency,* owing to the reduction of the scope for feed heating by bled steam.

Speed of steam raising was a function of the combustion arrangements, and a modern natural-circulation water-tube unit was as good as a forced-circulation unit in this connection. In any case, there appeared to be a tendency to overrate the advantages of *very* quick steam raising, as if starting with a cold job it was warming up the turbines which determined the time taken before getting under weigh.

Professor Mellanby had briefly ventilated the intensely interesting problem as to the best combination of pressure and temperature for the

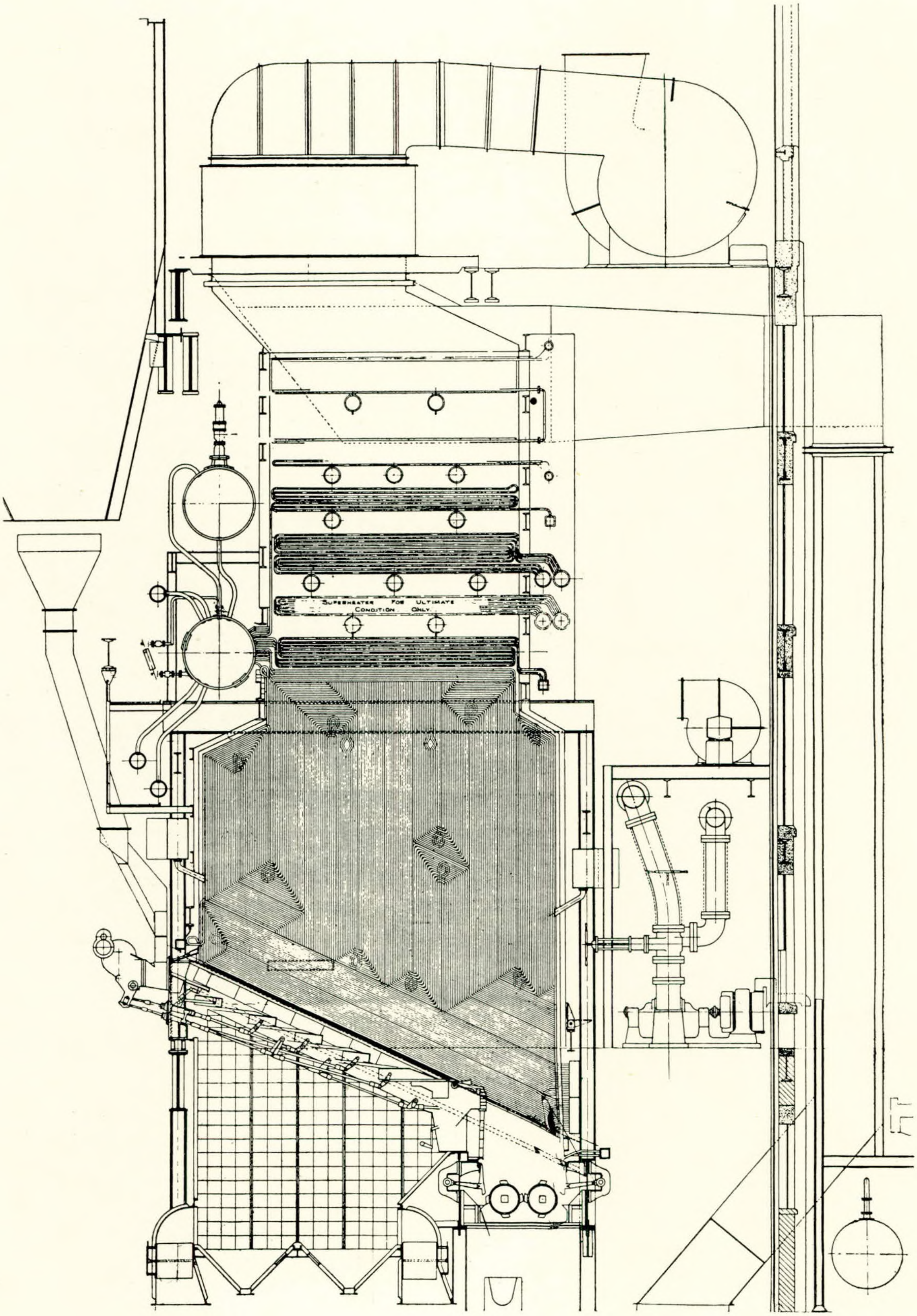

Fig. 20.

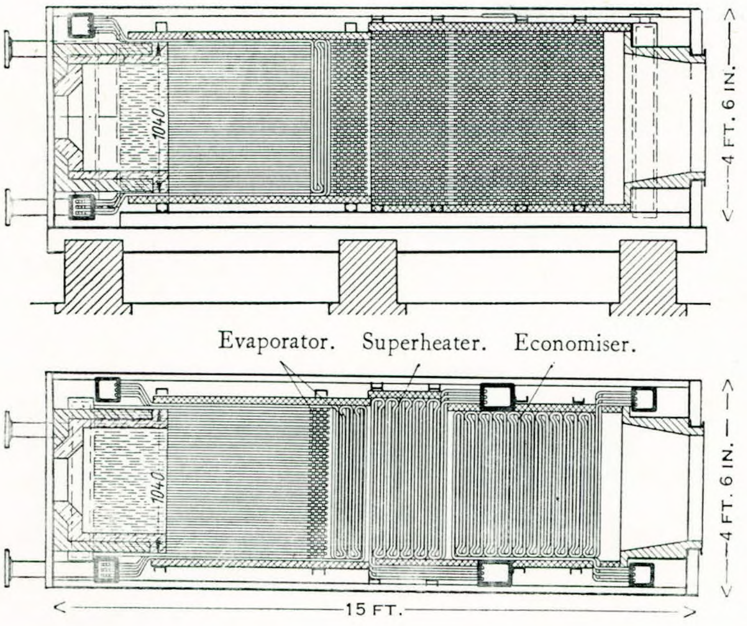

Fig. 21.

optimum economic marine steam cycle. His (the speaker's) present opinion was that for marine work there was little *nett* gain in exceeding about 500lb. pressure and 850° F. initial temperature (this latter keeping the superheater sections in their hottest zone within the limits of ordinary carbon steel) unless a reheat cycle were adopted. It was important to keep the study of marine steam technique quite apart from land considerations, as full power operation was normal practice at sea and many other fundamentals were so very different; whereas land developments formed an excellent basis on which to develop marine designs, marine requirements and practice must be the real determining factors.

Finally he would ask for some service consumption figures for ships fitted with these special designs of boilers. The true basis of comparison was fuel per s.h.p. per hour, including all auxiliaries, and in this connection he believed that ships fitted with natural-circulation water-tube boilers held all present economy records. In addition, maintenance and operating expenses were needed in order to get a true comparison.

Mr. R. E. Trevithick (Visitor) said that they must bear in mind that the following remarks applied principally to forced-circulation boilers of the La Mont type, of which there were over 500 either at work or on order, 90 of these being for marine purposes.

Whilst a strong case could be made for this design of boiler working at pressures below 400lb. per sq. in., the following claims could be considerably strengthened as the working pressure increased above this figure. Briefly and broadly these claims were (1) saving in space, (2) saving in weight, (3) flexibility to steaming conditions, (4) freedom of design to meet difficult conditions, and (5) high evaporation per sq. ft. of heating surface combined with a definite known factor of safety.

As regards saving space, Fig. 20 illustrated a La Mont boiler which was at present being built for the London Power Company. It had an evaporation of 350,000lb./hr. at a working pressure of 375lb./sq. in. and was being installed on the same space as a natural-circulation boiler having a capacity of 100,000lb./hr.

It was extremely difficult to give any reliable figures as to comparisons of weight, as so much depended on working requirements such as method of firing, working pressure, and overall efficiency required, but Fig. 21 would give some impression of what could be accomplished. This oil-fired boiler, which was only 4ft. 6in. wide by 4ft. 6in. deep by 15ft. long, was capable of evaporating 22,500lb. of water per hour, the steam pressure being 675lb./sq. in. at 800° F., the heat release being of the order of 650,000 B.Th.U. per cu. ft. per hour, the flue gas temperature leaving the economiser being 350° F.

As regards flexibility to steaming conditions, from results of sea trials on a La Mont boiler, with a working pressure of 800lb./sq. in., it was found possible to increase the steam capacity from 5 to 35 tons per hour in the space of one minute. Another example of flexibility in meeting steam demands was to be found in a pulverized-coal and oil-fired boiler recently installed. This boiler had an output of 224,000lb. per hour and could be brought up from cold to full load in 12 minutes.

As regards freedom of design, it should be appreciated that with forced circulation it was no longer necessary to arrange the tubes with a continual upward trend in order that the steam generated might get away by levitation, and it was for this reason that boilers could be accommodated in confined spaces.

The tubes used were usually of 1in. internal diameter, and these were laid at right angles to the gas flow; therefore the rates of heat transfer could be calculated with great accuracy.

With regard to the all-important question of feed-water treatment to which the author had referred, it must be appreciated that in all designs of water-tube boilers working at high pressure and highly rated, this matter must be given the most careful consideration. It must, however, be remembered that under high-duty conditions scaling and corrosion trouble were undoubtedly more pronounced in that part of the heating surface where circulation was known to be indefinite, whereas with a forced-circulation boiler this condition could not occur; moreover, it had been established that forced circulation had undoubtedly a scouring action on the internal surface of the tube. For these reasons he would be so bold as to claim that for equal working conditions a forced-circulation boiler could use a feed water inferior to that which a natural-circulation boiler would require.

The question of installing or omitting a drum had also been touched upon. It would be obvious that if no drum was fitted, then whatever entered the boiler as impurities in the feed must either stay in the tubes as scale or be carried over to the turbine. When a drum was incorporated, however, it was possible to control the concentration of the water in the boiler by orthodox blow-down methods, and, moreover, a steam washer of sufficient size to be really efficient could be accommodated, thus preventing carry-over to the superheater.

With regard to the author's question "Why do we want these very high pressures?", it was his (the speaker's) opinion that for marine purposes they did not. The working pressures must always be considered in conjunction with steam temperature. This temperature was governed by the material from which the superheater was made, and without resorting to complex alloy steels, which were expensive and inclined to be somewhat unstable, it was not advisable at the moment to call for a steam temperature above 850° F. Therefore, in order to avoid reheating, which was undoubtedly a very complicated refinement, the working pressure should be that which was best suited to the abovementioned temperature, and lay somewhere between 600 and 850lb./sq. in. For the present, therefore, he considered 850 should be the maximum.

A great deal of investigation and research was at present being carried out in connection with combustion, the object being to burn larger amounts of fuel per unit of space. These developments must inevitably be combined with greatly increased gas velocities and rates of heat transfer, and it was his opinion that these increased rates could only be safely absorbed by means of forced circulation.

Mr. S. McEwen (Associate) said that anyone referring to this paper in the future would wonder what was meant by the term "high pressure". Some of the pressures were very low. Pressures of 200 to 2,000lb. represented a wide range to be covered by the term "high pressure". For instance, performance figures were given of a Velox boiler, marine installation, operating at 230lb. pressure and it was clear that the objective of the designers of the Velox boiler was not operation at high pressures but to provide a boiler which would attain extraordinarily high rates of combustion and heat transmission and have a performance largely different from anything hitherto achieved. The Loeffler, Benson and Sulzer boilers described by the author were, of course, high-pressure boilers.

The author asked the question "why high pressure?". The answer to that was that as long as latent heat was being discharged into rivers and dissipated into the atmosphere, engineers would strive by every means possible to recover and save it. The means of accomplishing this were being thoroughly explored and advances in this direction were established by some of the plants described by the author. The objection that high pressures necessitated reheating ignored the fact that with the generation of steam at high pressure and temperature, reheating became simpler. On the "Conte Rosso", the Italian ship fitted with the Loeffler boiler (details of which were given in the speaker's paper published in the April, 1937, Transactions), there was a steam reheater, but it was far from being a complication. It was erected in the steam line and occupied little space. A high boiling point for the water at high pressure permitted a greater degree of preheating. With high pressure it was possible not only to preheat the feed water to a higher degree by bleeding the turbines, but since preheating became practicable the amount of heat which had to be dissipated as latent heat at the exhaust of the turbine was reduced.

Since the author asked for service results, the latest records of the "Conte Rosso" might be of interest. In his paper describing the plant on the s.s. "Conte Rosso" the speaker had given the actual performance of the installation; he gave therein the guaranteed figures supplemented by results of his own observations made on a trip when the vessel was in service. The following was a copy of the official minute made on January 5th, 1938, relating to the completed trials:—"At the official test trip made on the 2nd and 3rd instant, in presence of the representative of the Lloyd Triestino and of the Classification Societies, it was ascertained that the high-pressure plant, i.e., the Loeffler boiler as regards output and efficiency as well as the Escher Wyss plant as regards output and steam consumption, has fully met the engagements undertaken by the two contracting firms".

The Chairman announced that as it would be impossible to give all those who wished to take part in the discussion an opportunity to speak that evening, he would adopt a suggestion that the discussion be adjourned. A meeting would be arranged in March, when the discussion would be continued.

Eng. Rear-Admiral W. M. Whayman, C.B., C.B.E. (Vice-President) said that he had made the suggestion that the discussion should be adjourned in order that they should have an opportunity of hearing all those who wished to speak, and the fact that the Chairman had found it necessary to adopt this suggestion indicated the interest which the author's paper had aroused and the measure of thanks which was due to him. A symposium on high-pressure boilers was held at The Institute three years ago, and he (the speaker) recalled that many of the points raised this evening were discussed then, and this seemed to him an additional reason why the discussion should be continued and these questions thoroughly ventilated. Professor Mellanby would no doubt feel complimented that the interest his paper had caused necessitated this extended discussion, but he would formally ask those present to accord the author a hearty vote of thanks. This proposal was warmly carried.

The resumed discussion on this paper took place on Tuesday, March 8th, 1938, at 6 p.m. Mr. A. F. C. Timpson, M.B.E. (Vice-Chairman of Council) occupied the Chair and Professor Mellanby was again present.

Dipl. Ing. D. W. Rudorff (Visitor), on behalf of Dr. Hartman the inventor and designer of the Schmidt-Hartmann boiler, said that the s.s. "Altair" mentioned in the paper started on its maiden trip on November 1st last year. During basin trials held the day prior to the departure, a mistake was made in the operation of the feed-water plant, with the result that considerable amounts of fuel oil were discharged into the boiler drums, where the oil obviously did not belong. This mistake was not noticed until about four inches of oil had accumulated in the drums. To remove this fuel oil prior to departure proved impossible, and the maiden voyage had to begin with oil accumulations in the boiler. The boat went first to Amsterdam, from there to Antwerp, and then to Libau and Riga, with the boiler operating perfectly satisfactorily in spite of its oily condition. In Libau sufficient time was available to open the drums and to inspect the evaporator coils.

They were found to be covered on the outside with an oil and scale accumulation about $\frac{3}{16}$in. thick; this was removed as far as time and circumstances allowed. Only when the vessel had returned to Hamburg for a stay dating from December 12th-18th, could a somewhat more thorough cleaning be effected. On the 18th the boat left for Colon (Panama Canal) where it arrived on January 11th, which was one day ahead of schedule. An engineer of the Argo Line who acted as special inspecting engineer during the trip summarized his observations during the voyage as follows:—

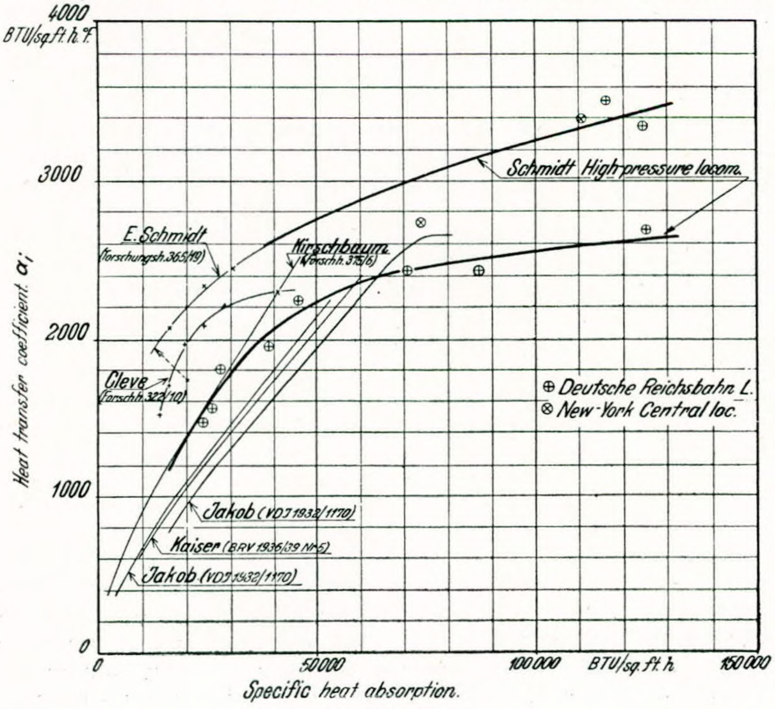

FIG. 22.

> "The boilers have given excellent results during the journey. The maximum steam output was limited to seven tons per hour by the capacity of the oil burners. With this output the pressure in the primary boilers was found as 1,263lb. per sq. in. and that of the working steam as 695lb. It will therefore be quite easy to obtain the specified maximum output of 8·25 tons per hour, once sufficiently large oil burners are installed. By carefully supervising the feed-water supply and adding tri-sodium phosphate the primary pressure could be kept absolutely constant for the four weeks of continuous operation at constant engine load. To judge from the constancy of primary pressure, the evaporating elements remain absolutely clean".

The report also mentioned that the main condenser was leaking for three days. The leakage was finally suppressed by introducing sawdust.

He believed they would concur with Dr. Hartmann that these experiences were a very convincing additional proof of the author's statement that "the Schmidt boiler has the greatest margin of safety".

The Argo Line had now ordered a sister boat to the "Altair" and this would also be equipped with a Schmidt-Hartmann boiler. The engineers of the North German Lloyd appeared to have been very much impressed with the performance of the boilers in the "Altair", and they had ordered two Schmidt-Hartmann boilers of a capacity of 10 tons of steam per hour each at 500lb. per sq. in. pressure for the North German Lloyd freighter "Porta" which was being converted to steam turbine drive. The "Porta" was a vessel of 4.162 register tons. These boilers would be equipped with travelling grates.

Furthermore, three steam tugs for canal service were now being equipped with these boilers each with a steam output equivalent to about 300 h.p. These boilers would be equipped with chain-grate stokers. There were now 51 Schmidt-Hartmann boilers in operation or on order with a combined steam output of 3,700,000lb. per hour.

The author had given a very illuminating exposé of the problem of ensuring a sufficiently high rate of heat transfer from the inner tube wall to the water-steam mixture flowing through the boiler tube. In this connection the accompanying illustration (Fig. 22) gave the heat transfer coefficient from tube wall to the water-steam mixture. In this graph the heat transfer coefficient a from the tube wall to the water-steam mixture was plotted against the specific heat absorption, which was derived from the total output of steam from the tube. For the heat absorption of 90,000 B.Th.U. mentioned in the paper they would find an a of 2,500 B.Th.U. per sq. ft. per hour per degree F. temperature difference in the case of the test made on the Schmidt locomotive built in Germany, and 3,200 B.Th.U. per sq. ft. per hour per degree F. temperature difference in the case of the test made on the Schmidt locomotive built for the New York Central Railroad. As the trend of the two curves indicated, the coefficient a rose to even higher values with increasing heat absorption.

It had been found that two limiting values existed for the coefficient a under given test conditions. The upper limiting value was found when the test was begun and the lower value after long-time operation. This fact had also been ascertained by M. Jakob*, who gave an explanation for this phenomenon, which was not due to scaling of the tube wall.

Once the coefficient a was known, it was possible to compute the outside wall temperature of the tube and to compare it with the result of actual temperature measurement by means of a thermocouple.

Actual tests had shown a good agreement between computed and measured temperature. Even at highest loads the outside wall temperature of the tubes of greatest heat absorption in the Schmidt-Hartmann boiler lay not higher than between 752-842° F.

When speaking of forced circulation, they were easily inclined to think that this implied much higher circulation ratios of water and steam in the tube than could be obtained with the thermosyphonic circuit. Actually, however, the circulating ratio in the case of the Schmidt-Hartmann locomotive built in Germany had been measured as 10·3 to 1 at 1,290lb. per sq. in. pressure in the primary system, and it was found to be 12·7 to 1 when operating at 925lb. per sq. in. primary pressure. The water-steam ratio in the tube of the thermosyphonic boiler lay, therefore, even above the usual ratio of 8 to 1 employed in forced-circulation boilers. He might add that the inner tube diameter of the German Schmidt locomotive tested was 1·65 inches.

It was interesting to note that the velocity of the steam-water mixture in the tubes had no influence upon the magnitude of the coefficient a. All that a higher circulation velocity effected was a more rapid disengagement of the steam bubbles from the inner tube wall. Furthermore, forced circulation could not suppress the formation of steam and air cushions in the return bends of tube coils, and this could lead to excessive tube metal temperatures and corrosion and to the final destruction of the tube.

The author referred to the danger of salt deposits in the turbine due to carry-over of salts and impurities with the steam. According to operating experiences with high-pressure boilers in a large chemical works in Germany, the salt content of the steam condensate amounted in the case of Schmidt-Hartmann boilers to only two to three parts per million even at pressures above 1,420lb. per sq. in., no matter whether condensate of 30 p.p.m. concentration or chemically-treated water of 500-700 p.p.m. was used as feed with a salt concentration of up to 30,000 p.p.m. in the boiler. The Schmidt-Hartmann boiler was therefore particularly suitable for turbine operation when no condensate was returned and 100 per cent. of the feed water must be chemically treated.

Dr. Hartmann, however, believed that the largest field of high-pressure steam application was represented by freighters and tramp steamers and not by super liners. Freighters and tramp steamers were mostly driven by reciprocating engines. A salting-up of the engines could of course not occur, but excessive carry-over could result in an excessive wear of the piston rings. Furthermore, in engine operation there was always the danger of cylinder-oil entering the boiler, and for such conditions—also including the danger of condenser leakage—the Schmidt-Hartmann boiler would appear to be particularly suitable.

Mr. A. W. Richardson (Member of Council) said that the author referred to it being the practice in America for land type boilers to be operated at a heat release of about 30,000 B.Th.U. per cu. ft. volume, rising occasionally to 50,000 B.Th.U. In tests carried out on a B. & W. marine boiler of a type of which thousands were in use, a heat release of over 200,000 B.Th.U. per cu. ft. furnace volume had been obtained on a rating of 1·0lb. of oil per sq. ft. of tube heating surface at a boiler efficiency of 80 per cent. and when the rate was increased to 1·5lb. of oil per sq. ft. of heating surface a boiler efficiency of 76 per cent. was obtained.

The furnace volume was not all that was to be considered, as the writer had known cases where a heat release of 50,000 B.Th.U. gave better results than with 25,000/30,000 B.Th.U. per cu. ft.

The author also referred to a special feature of the Velox type boiler being the rapidity with which it could be put on load, and that claims were made of it being possible to start up from cold in ten minutes. The writer witnessed a demonstration a few days ago in a large electric power station where

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* M. Jakob. "Heat Transfer in Evaporation and Condensation". "Mechanical Engineering", Vol. 58, 1936, pp. 643-660.

a standard B. & W. marine type land boiler of over 200,000lb. evaporative capacity was put on load from cold within 12½ minutes, including the time taken to start up a turbo-generator also from cold required for supplying electric current for the fans and fuel oil pumps. Actually steam on this boiler could be raised in very much less than ten minutes if water-cooled walls were installed and electric current available for starting up, but special conditions in this case called for a separate turbo-generator.

A notable feature of this plant was that positively no smoke must be made either during lighting-up or whilst the boiler was on load. He would like to see such a test carried out on any of the boilers referred to in this paper.

For marine purposes oil could be taken as the fuel best suited for the type of boilers under discussion. It was unfortunate that the author did not dwell on the type of burner best suited, i.e., straight pressure atomising or rotary cup type, as although it was important that a burner be efficient, it must be correctly applied in order to secure the full benefits of its design.

Mr. G. H. Forsyth, M.Sc. (Member) said that the author referred to a stress of 10 tons per sq. in. on the inside of the superheater tube when the calculation was based on the elastic theory. The author also mentioned the work of Dr. R. W. Bailey in connection with heat stresses. He (the speaker) had made a careful study of the work of Bailey and he considered that it related to a plastic theory. Probably the author would agree with that.

There seemed to be two ways of calculating tube stresses. One was the elastic theory and the other was Bailey's purely plastic theory. He considered that in practice the tube would work somewhere between the two conditions, but he would like the author's views on this point.

Bailey's experiments were carried out on materials in their plastic conditions, and he excluded entirely elastic conditions. The speaker did not consider this could be done with superheater tubes, because for these he thought that elastic as well as plastic conditions were important. Another point was that when the tubes cooled down to normal there would be stresses in them (assuming plastic flow took place) and it would be necessary to subtract elastic stresses. The more you worked in the plastic range the more stress there would be in the tube when cooled, and the more you worked in the elastic range the less would be the stress in the tubes in the cold condition. He would appreciate the remarks of the author on this question.

Mr. V. B. Harley-Mason (Visitor) said that the author made two references to rates of heat transfer and invited discussion on this point. In the first reference at the bottom of page 54 he drew a comparison between the heat-absorbing capacity of water alone and that of a steam-water mixture. The second reference was on page 58 where he compared the relative heat-absorbing capacity of a steam-water mixture with that of superheated steam. In this connection the results of some actual trials made by the Swedish Academy of Engineering on the heat transfer rate in tubes containing various steam-water mixtures would be of interest. Referring to Fig. 23, the horizontal scale was percentage of steam by weight in the mixture starting from zero at the left-hand side to 100 per cent. at the right-hand side. It might also be taken (though not strictly to scale) as representing the length of a tube through which water was flowing from left to right.

Against this, various values were plotted. As the amount of steam in the mixture increased so the total volume increased and hence the velocity increased—this was shown by curve A which was a straight line.

The total amount of heat absorbed was shown by the curve B which was also a straight line. The percentage *volume* of water in the mixture was surprisingly small and was shown by the curve C. The last and most interesting curve was D, which indicated the rate of heat transfer. This showed that although the percentage of water by volume was small and decreasing, the rate of heat transfer

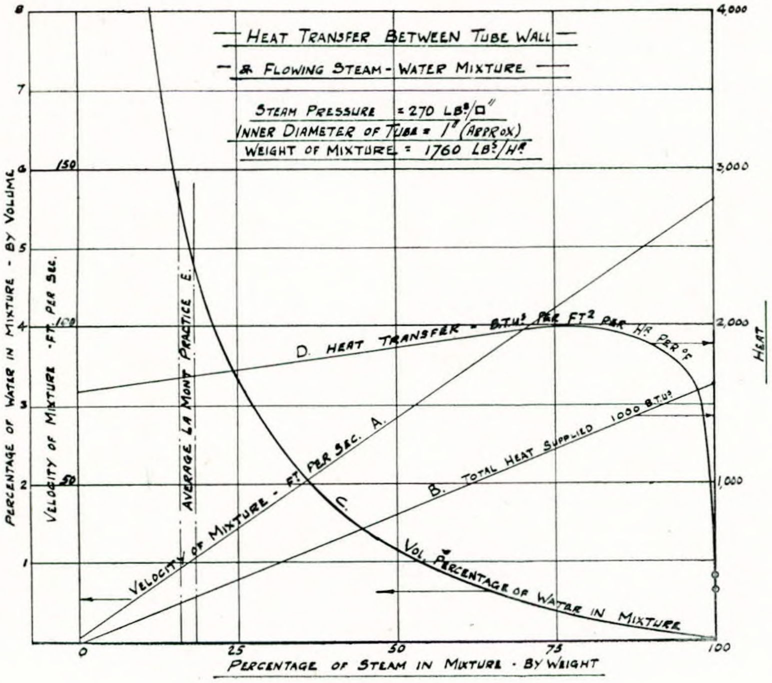

Fig. 23.

actually increased slightly (apparently due to increased velocity) until the volume of water present had diminished to about 0·5 per cent. The transfer rate then decreased rapidly until the dry steam condition was reached.

It was usual in La Mont practice to circulate about six times the maximum evaporation, i.e., to evaporate about 16 to 17 per cent. of the water present. This was indicated by the vertical band E at the left-hand side.

Referring again to the total heat curve B, it would be seen that at this point the tube would have received some 240,000 B.Th.U., whereas it was capable of receiving about 1,200,000 B.Th.U. before the danger point due to falling heat transfer was reached. In other words there was a thermal factor of safety of five.

Mr. G. T. Marriner (Associate Member) said that there was no doubt that certain remarks in the previous discussion of the paper in favour of straight-tube natural-circulation boilers deserved serious consideration, and it was perhaps opportune to mention that during the last few weeks a contract was placed for a natural-circulation boiler having a maximum capacity of 550,000lb. of steam per hour to operate on 1,420lb. pressure and a final steam temperature of 965° F.

While it was admitted that these high pressures and temperatures were for land plant, one must bear in mind that a unit of this size would not be ordered unless the engineers responsible were quite satisfied that it would be a thoroughly practicable proposition. Therefore, after allowing the necessary additional margin required in marine engineering, there did not appear to be any reason why natural-circulation boilers should not be at least as economically sound as regards desired temperatures and pressures as the various complicated forms of heating surfaces and their auxiliaries described in the paper.

It would be noted that in every high-pressure boiler described, the most simple form of combustion was assumed, i.e., oil fuel. What was to happen to these boilers if the shipowner was interested in burning coal? Every design illustrated would require radical modification and, in fact, in many instances it would be impracticable to consider the application of mechanical stokers.

Some might feel this could be overcome by using pulverized fuel, but in this connection he need only ask them to refer to those who had tried this experiment for their candid opinion of this system of burning coal at sea. Having just completed a study of all the known ships in the world fitted with mechanical stokers, which incidentally would shortly number eighty, he found that in no case where pulverised-fuel equipment had been fitted was the experiment ever repeated and in many instances the plant was taken out.

He had purposely eliminated the question of hand firing these boilers, because if one was going to the trouble of obtaining the last ounce in the engine room by utilizing high pressures and temperatures, it was not logical to consider using a shovel in the stokehold, especially with high superheat.

Mr. T. S. Blenkinsop (Visitor) said that since the previous discussion on this paper his Company had received full details of the tests on the high-pressure installation in the s.s. "Conte Rosso" con-

OFFICIAL TRIAL RESULTS S.S. "CONTE ROSSO".

TRIAL No. 1.

Boiler plant: 1 Loeffler boiler plus 6 double-ended Scotch boilers during trial of 12 hours.

GENERAL PERFORMANCE OF COMBINED PLANT.

Total power developed	20,600 s.h.p.
Average speed of propeller shaft	95·87 r.p.m.
Total oil consumption	18,975lb./hr.
Oil consumption per s.h.p.	0·921lb.
Speed of vessel	19·99 knots/hr.

PERFORMANCE OF H.P. PLANT.

Loeffler Boiler.	
Output	45,320lb./hr.
Average steam pressure	1,920lb./sq. in.
Average steam temperature	921° F.
Average feed temperature	228° F.
Oil consumption	3,762lb./hr.
Calorific value	17,388 B.Th.U.
CO_2 at boiler outlet	12·75 per cent.
Flue gas temperature	325° F.
Boiler efficiency	89·3 per cent.

H.P. Turbine.	
Steam quantity	42,526lb./hr.
Indicated output	2,560 s.h.p.
Thermodynamic efficiency	77·7 per cent.
Steam consumption per s.h.p.	16·6lb.

TRIAL No. 2.

A comparative test lasting 16 hours, divided into two periods of 8 hours. The first period with Loeffler boiler and four double-ended Scotch marine boilers; the second period with six double-ended boilers only in operation.

TEST RESULTS.

	FIRST PERIOD. *1 Loeffler and 4 Scotch Marine Boilers.*	SECOND PERIOD. *6 Scotch Marine Boilers.*
Speed of vessel	18·28 knots per hr.	18·38 knots per hr.
Power developed	15,000 s.h.p.	15 060 s.h.p.
Oil consumption	14,630lb./hr.	15,774lb./hr.
Oil consumption per s.h.p.	0·976lb.	1·05lb.
Saving in fuel per hour	1,144lb.	
Saving in fuel per 24 hours	12·26 tons.	

sisting of a Loeffler boiler and Escher Wyss turbines, as referred to in Mr. McEwen's paper read before The Institute in March, 1937. From these tests he had extracted the essential particulars which were likely to be of interest to members of The Institute, and these particulars were reproduced on page 76 in the form of two schedules.

Continuing, Mr. Blenkinsop said that the test results confirmed the guarantees given, and as such had been accepted by all parties concerned. He hoped that these figures would be of interest when considered in conjunction with Mr. McEwen's paper.

Mr. J. Reid (Visitor) said that he did not wish to be considered a reactionary who desired to maintain the Scotch boiler against the types described by the author. As much of his work was associated with the water-tube boiler he had no prejudice against it. His chief objection to these high-pressure boilers was that they could not be run under manual control. It would be necessary to put in combustion control much more positively than in existing high-pressure boilers.

It was generally assumed that the Scotch boiler could not take the rates of heat release and transmission through the furnace walls claimed for these modern high-pressure boilers. That was not right! Considering the Velox boiler shown in Fig. 5, it would be noticed that the furnace looked very like that of a Scotch boiler with the hollow walls up on end. On page 57 they were told that heat transmission rates of 100,000 B.Th.U. per sq. ft. per hour were in common use in the Velox boiler. He hoped his veracity would not be doubted when he stated that they had been up to that figure over certain furnace zones nearest the oil burning flames for 10 or 12 years in Scotch boilers. The reason why these rates could be run up to in a Scotch boiler furnace with perfect safety was that by reason of the special turbulence in the tubular furnace a wonderful development of flame could be obtained and combustion completed in about half of the furnace length. Incidentally, the Scotch boiler had the first water-walled boiler furnace. One might think that because they were so thick the walls would overheat. That was not right, either! He discovered that in running up to these high rates the radiant heat struck through into the tubular furnace and travelled along the furnace barrel at a rate which was not appreciated when he first started.

With regard to Fig. 1, it could be assumed that there was a very high temperature at θ_1, and heat was trying to cross the tube. The tube could not become overheated because by a process which he thought they did not yet quite understand (the author gave a clue when he stated that alloy steels changed the rate), this heat did not strike through to the water direct but spread itself along the metal. The metal thickness in the case of a Scotch boiler furnace was quite an asset in such matters.

The author gave a formula for obtaining approximately the radiant heat transmission in a boiler furnace. That formula was about 75 years old, and many engineers had studied and tried to use it. It was one of the simplest-looking formulæ one could come across, but he had never met anyone who could tell him how to find either T or θ.

One point which he wished to stress was that it should be more fully realized that furnace efficiency was based upon radiation, and boiler efficiency and economy upon furnace efficiency.

The author stated, and he was inclined to agree with him, that the heat transmitted by radiation to the heating surface varied from 45 to 60 per cent. of the calorific value of the fuel. He had been told that 50 per cent. was all that could be got out of radiation and that one should be satisfied with that. He did not know whether the author shared this point of view. He was afraid that his (the speaker's) veracity might again be doubted when he claimed that they had no difficulty in getting 70-75 per cent. through the furnace walls of a Scotch boiler by radiation. The Scotch boiler was interesting to experiment with; it was solid and could easily be kept clean. Every fire had its own individual character and control, and because of the tubular character of the furnace one could swing the oil flame and get turbulence to an extent that could never be done in a water-tube boiler until the water-tube designer got his furnace as near as he could to the Scotch boiler furnace. The Schmidt-Hartmann boiler furnace shown in Fig. 15 was as near to the Scotch boiler furnace as it was possible to get. They would note the single fire, the large brick ring around the flame and, most interesting of all, near the lower drum they would note the brick platform under the flame.

The La Mont boiler shown in Fig. 3 was unfortunately not quite in accordance with the photographs of the actual boiler built at Clydebank. The furnace was quite square, and the tubes came down close to the brick backing. There were seven fires in the air casing. The air registers which seemed to be intended to go into the holes shown in Fig. 4 looked to him to be primitive. As far as he could see there did not appear to be any effective subdivision of air supply to the fires, which apparently were working in a common air box. Could you keep control of the combustion at different rates of loading in that furnace? He did not think it could be done, with the result that even under moderate air pressures in the stokehold the flames would be developing too late and the gases separating out and getting away unburnt through the tubes to the roof. That brought out his point that a good boiler efficiency could not be obtained without a good furnace efficiency and combustion control. This fact probably explained the comparatively low boiler efficiency in these trials, although he had always considered that for naval vessels efficiency was dropped to get the advantage of comparatively small weights and space.

What was it that prevented their own boiler designers from bringing out boilers corresponding to those described in the paper and considered so successful in Continental practice? What had happened to the famous boiler designed, built and tried for British destroyers and then discarded? What also had happened to the Velox boiler ordered from a British firm for warship work—they had heard nothing about it lately? He was inclined to agree with several speakers that there was no reason why they should yet discard the natural-circulation boiler, but effective natural circulation was always a reflex of combustion control.

Eng. Rear-Admiral W. R. Parnall (Member) said he thought there was no doubt that all the various boilers the author had described were practical propositions. Many of them indeed were operating in large numbers.

The question which had exercised his mind was why people were trying these new types of forced-circulation boilers, and he thought the reason lay in the fact that they anticipated greater overall economy, greater reliability, or, more probably, a saving of weight and space.

Many of these boilers were designed to work at high pressure, but it was brought out in Mr. Cook's paper read before The Institute in January last, that in going beyond pressures of 750lb. special arrangements had to be made to condition the steam if difficulty with water at the exhaust end of the turbine was to be avoided. It was not advantageous to use really high pressures and temperatures unless they were going to get a return which was comparable with the theoretical economy and without giving rise to difficulties or deficiencies in other directions.

With regard to saving in weight and space, the three-drum boiler which was used almost exclusively in the naval service was capable of producing a weight of steam which was remarkable when compared with the weight of the boiler. In the paper read in 1936 by Admiral Dight before The Institution of Naval Architects he stated that he had run an ordinary three-drum natural-circulation boiler to a rate at which it produced 1·6 tons of steam per hour for every ton of boiler. None of the figures he had seen quoted for these new boilers indicated more than about half a ton of steam per ton of boiler.

At the high figure quoted the efficiency of the three-drum boiler was considerably lower than when working at a more modest rating, while the Velox boiler for example, on the contrary, would give a high efficiency at its full output. The output of this latter type of boiler he believed, subject to correction, had a ceiling like a Diesel engine, beyond which it could not be forced.

When considering weight the output might be presented in the following way: The boiler would produce so many tons of steam per ton of boiler (*a*) on a basis of maximum output, and (*b*) on a basis of maximum efficiency, which as the author indicated on page 64 was much the same for all types. He hoped it was the intention of the author to make comparisons of the relative merits of the various boilers and, on the aspect of weight and space, he (the speaker) would be glad if he would differentiate between these two bases, i.e. maximum output and maximum economy. The figures would be quite different.

Mr. V. B. Harley-Mason (Visitor), speaking again in answer to some of the comments on the La Mont boiler, said the fact that the combustion chamber in Fig. 4 was square had aroused criticism, and they had been told that the oil firing arrangements were crude and it would be impossible to control combustion.

No-one must take it that because this combustion chamber was square the combustion chambers were always square. One of the chief features of the boiler was that due to the forced circulation and to the fact that the designer was not hampered by ordinary considerations of natural circulation, etc., he could make the boiler any shape he liked. Boilers were sometimes made without drums, sometimes with the drums in another room and so on. The reason that this combustion chamber was made square was simply that the conditions demanded it.

With regard to the question of furnace efficiency, they must think of the boiler and the oil firing apparatus separately. It was the business of the oil fuel installation to burn the fuel. It was the business of the boiler to catch the heat generated. It was obvious that if the furnace was not efficient the boiler could not be efficient. In the particular instance criticized the oil burning arrangement was by the Admiralty, and the La Mont Company were not responsible for it. The air box was provided with divisions and it was possible to control combustion.

Regarding output, one speaker mentioned that none of the boilers mentioned in the paper had claimed for it an output of more than half a ton of steam per ton of boiler, whereas the three-drum boiler would give an output of 1·6 tons. The boiler illustrated weighed about 40 tons and it was run up to an evaporation of 120,000lb. per hour, which was about 55 tons. This gave a figure of 1·3 tons of steam per ton of boiler. The La Mont boiler could have given more if it had been given more fuel and more air, as was done in the case of the three-drum boiler.

Mr. A. R. Paterson (Member) said that the service results given in the paper and discussion had all been from the point of view of the makers of the various boilers. It would be invaluable if the author could give them some service results from the point of view of the marine engineer. Comparative figures were of great interest, but the operating engineer wanted information on the troubles that were likely to occur with these boilers, where to look for these troubles and how to deal with them.

On the proposal of **Eng. Rear-Admiral W. M. Whayman, C.B., C.B.E.** (Vice-President), seconded by **Mr. A. W. Richardson** (Member of Council), the author was enthusiastically accorded a vote of thanks for his highly successful paper.

By Correspondence.

Mr. B. Stephenson (Member) wrote that in considering the valuable information given by Professor Mellanby, perhaps one of the most significant points raised was in the figure for the relative heat conductivity of plain and alloy steels and the bearing this had upon the size of tube adopted.

Referring to Fig. 1 showing temperature gradient across a tube thickness, was it possible that in addition to the drop $(\theta_1 - \theta_2)$ there were further differences due to resistance to initial heat penetration into the outer surface of the tube material, and similarly to resistance to exit through the inner surface to the steam-water mixture inside? If so, then these might somewhat modify the figures for conductivity relationship.

As about 60 per cent. of the heat absorption took place in the walls of the combustion chamber, it would be of interest to know whether it had been found necessary with the small diameter contiguous tubes to adopt any special means for keeping these clean. Would the standard types and usual arrangements of soot blowers be found satisfactory when using pulverized and liquid fuel of varying qualities as obtained in different ports?

In cases where ferrules with adjustable orifices were fitted to control the quantity of water passing to a tube, was there any tendency to eddy formation and for occluded gas to collect in the tubes at the entry end? With this form of construction were cover plugs with joint rings usually fitted in the headers opposite each tube end?

Steam drums positioned away from the hot zone, although adding to weight and cost, were a good feature and he desired to know whether the drumless boilers could be relied upon to respond quickly to sudden demands for increase of speed and quick changes as in manœuvring.

Referring to Professor Mellanby's closing remarks, it would seem that the contest for economy in ocean transport together with the trend towards higher speeds, and in particular with warships the necessity for reduction in machinery weight, were responsible for the increases in pressure now being adopted in marine boilers.

Apart from naval work, the pressure for maximum economy must be considered from both the theoretical and commercial standpoints, for the shipowners' demands called for a reasonably low capital cost combined with small fuel consumption, small space occupied and low weight. The plant must also be suitable for use with the classes of fuel likely to be obtained in general service, the upkeep must be small and reliability must be such that no time was lost in port repairs.

Mr. J. E. M. Payne (Member) wrote that from the paper it appeared the marine boiler might evolve from the present-day self-contained unit into a group of units each designed for a specific purpose and playing an essential part in the boiler circuit.

The reliable Scotch boiler was not always free from trouble, and it was in those parts of the boiler circuit, subject to high temperatures, where the products of combustion changed their direction of flow (or formed eddies) that cracks appeared or erosion took place. Was erosion experienced, for example, at the point where the gases reversed their flow in Fig. 5 at the bottom of the combustion chamber, or again where work was done on the compressor turbine blades?

The neat layout of the power station illustrated in Fig. 6 suggested that the day might come when ships of high power and speed might be fitted with boilers and turbines in one compartment with a simple main steam connection. The auxiliary power could be quite independent and designed on efficient lines. For inspection and upkeep purposes such a boiler would be mounted well clear of hull structure, and from this point of view its general shape presented an interesting problem.

Presumably the long tube elements in, for example, Fig. 13 were built-up by electric welding and information would be welcomed as to how these welded joints behaved under such severe conditions.

Judging by experience gained on repairing by electric welding the combustion chambers of Scotch boilers, it was important that surplus weld metal be avoided on surfaces subjected to radiant heat.

The cleaning of the tubes on the furnace side appeared to present a problem, notably in Fig. 11, and some form of mechanical scrape would appear desirable.

Centrifugal pump impellers were often severely pitted, particularly when dealing with aerated fluids and fluids delivered at a speed greater than the critical velocity. The safe working of some of the boilers described by the author would evidently depend upon close attention being paid to the circulating pump.

The author seemed to imply by his opening and closing remarks that he doubted the wisdom of employing very high pressures and temperatures and the writer wished that he had enlarged on this theme, although it was rather outside the scope of the title.

Judging by the descriptions given, it could not be urged that these boilers were intrinsically complicated, and the added complication of interstage heating might eventually be worth while.

It was remarkable that although the gain due to a high superheat temperature was small if calculations were based on the Rankine cycle, the actual saving in fuel was considerable.

The writer remembered an incident at sea on a twin-screw liner with single-reduction geared turbines working at a pressure of 215lb. per sq. in. and a temperature of 700° F., representing a gain of about 2 per cent. over saturated steam conditions in Rankine efficiency. The main steam range had to be changed over to saturated steam for about an hour and to maintain speed the size of burners had to be rapidly increased. In such a case it would be instructive if measurements of consumption were compared.

In pre-war days corrosion was a common occurrence on economiser tubes and now the economiser appeared in new guise. This form of corrosion was sometimes attributed to sulphur in the uptakes at a temperature below the dew-point, but the cure for this was self-evident.

Mr. W. H. Revill (Member), in a written contribution, asked what was the proved and tested water gauge in standard use on the generating drum (or drums) on Loeffler boilers, and was a secondary check device fitted (such as an alarm whistle) to warn should the feed control fail?

Mr. J. Hamilton Gibson, O.B.E., M.Eng. (Vice-President) wrote that he was particularly interested in the author's general remarks on heat transmission and agreed as to the importance of the cleanliness of the water or steam side of the heating surfaces. But what about the gas side? The insulating effect of soot deposits was very considerable and quite capable of upsetting the designed distribution of heat throughout the successive boiler passes. Dirty fire-row tubes failed to extract their quota of heat from the combustion gases, and consequently superheaters, air heaters, etc., became overheated sometimes with dire results.

Presumably similar effects occurred in the new types of forced-circulation boilers, and one would like to know what provision was made to maintain their gas surfaces clean and efficient.

In his opinion these new steam-producing machines would never become popular in the British Mercantile Marine. Forced-circulation pumping apparatus was an added complication which would not appeal to seagoing engineers. What happened in case of temporary failure of the apparatus; would the boiler function at all?

Marine engineers would no doubt study this paper with the idea of spotting something useful that might be applied to existing boilers which, as was well known, had not had their possibilities fully exploited even yet. The improved forms of Scotch and water-tube boilers due to Mr. John Johnson had shown how output might be safely increased, and it was worthy of note that their furnaces and combustion chambers were entirely water-walled and could thus deal with a high heat release. The Johnson water-tube boiler on test recorded a heat release per cubic foot of combustion chamber exceeding 300,000 B.Th.U. with natural water circulation and normal forced draught.

A common feature in the new types of boiler described was one that had been strangely neglected in marine practice, though (to their credit be it stated) their American and Continental friends were evidently alive to its advantages. He referred to the economiser now almost universal in land practice. In some low-pressure marine boiler installations of a century ago gravity feed tanks in the base of the funnel were used, and fifty years ago tubular economisers were fitted in uptakes, but were found to corrode rapidly. Pure feed water had got over that difficulty as regards the insides, and gilled sleeves of cast-iron shrunk on the tubes protected their outsides from corrosive soot deposits, besides increasing the effective heating surface by five or six times. In this connection it was interesting to refer to Mr. W. A. White's paper read before The Institute in April, 1937, when he claimed a coal consumption of ·9lb./i.h.p./hour (all purposes) for his "economy" engine, and pointed out that by driving the auxiliaries from the main engine and installing a feed heater (economiser) in the uptake, the fuel consumption would not exceed ·75lb.

These were merely indications of some of the tips to be gleaned from a study of Professor Mellanby's comparisons and analyses. Whether they were impressed by the new steam raisers or not, they should be encouraged to adopt and use these tips for the improvement of the various types of boiler which were serving them so well at present.

Mr. W. W. Adamson (Member) wrote that the tensile test figures given for the welded tube specimens shown at the current British Industries Fair of parts of the La Mont type of boiler were as follows:—

1¼in. welded steel tube, 0·136in. thick, 1·241in. ext. dia.;
Ultimate strength 26·5 tons per sq. in.;
Yield point 18·8 tons per sq. in.;
Final extension in 8 inches, 25·7 per cent.;
Silky fracture, broke clear of weld.

The same type of tube with the welding metal buffed off flush with the tube walls gave the following results:—

1¼in. welded steel tube, 0·126in. thick at welded portion;
Ultimate strength 24·3 tons per sq. in.;
Yield point 20·1 tons per sq. in.;
Final extension in 8 inches, 4·7 per cent.;
Broke at weld.

The tubes were welded by acetylene flame externally with the tube ends butted, and there was little, if any, weld metal penetrating into the interior of the tube. The mechanical test figures were of course satisfactory, but to allay any prejudice against this method of manufacture it was necessary to consider any possible defects.

Firstly, the material stress curve appeared to be still falling from its pressure stress to the turning point at which it rose under the heat stress for this type of tube, and the laying on of welding metal over the weld did not therefore increase the stress in the material for all ordinary rates of evaporation.

Secondly, the grooving of weld metal on water-heating surfaces did not appear likely to arise unless there was any considerable amount of weld metal penetrating into the water space of the tube. There was, however, a considerable variation in the elasticity of the tube at the weld, as shown by the test figures given above, at its ultimate limit.

Thirdly, the coefficient of conductivity K for weld metal might be assumed as being less than that of the body of the tube without, perhaps, producing any local heating in the new boiler. There was, however, in the diagram of temperature drop, that shortest distance between two points from theta one to theta two usually given as an estimate. The conductivity of the copper firebox of the locomotive was very high, but it had also been assigned a rather unfortunate quality ascribed to a very low emissivity; this was negatived by its high rate of forced circulation when running at speed on a jolting track with the result that the locomotive boiler was a very efficient steam producer.

Fourthly, the scale in a steam boiler settled where the circulation was sluggish or impeded—not where steam was being produced, but where it was not being produced. Whether scale would settle at a weld due to any roughening of the tube impeding the speed of water from the circulating pump nozzles, due to its lower conductivity and lower emissivity, or whether there was a greater tendency for scale to collect at the tube bends where the area was reduced by the flattening of the sides of the tube walls, would be most usefully shown by some of the service results of some of these tubes, if they were available and had ever been removed.

Mr. E. S. Dean, B.Sc., wrote that the primary object of the paper and of the discussion was to focus attention and to promote an exchange of ideas on the behaviour in service of high-pressure marine boilers.

The operating experience which they had had with the Velox boiler in the marine field was limited to certain naval type boilers and to the 76,000lb./hr. unit on the "Athos II", working at 685lb./sq. in. and 840° F. and referred to at the bottom of page 57. Nevertheless, the observations made on this limited number of marine units, together with the more extensive experience with the 50 odd steam generators for stationary purposes and operating up to 1,140lb./sq. in. and 940° F. might be of some interest, particularly as the various problems which had arisen had been tackled from a new view point.

First of all, he would preface his remarks by a few words regarding the question "Why a very advanced type of boiler and why high pressure?" It had been pointed out that such advanced equipment and steam conditions involved certain attendant disadvantages, such as a higher standard of operating staff and a much closer control of operating conditions. This was quite correct, but, as in the past, these factors were only incidental provided a nett gain in £ s. d. could be shown in service. The steam turbine and Diesel engine had largely superseded the reciprocating engine, although completely new standards in operating staff and conditions were called for; in the same way, these factors would not hinder further progress, but would, of course, increase the time-lag. It was necessary, however, for any new equipment to prove in service that worthwhile gains could be effected and it was in this respect that practically all of these newer types of steam generator were, as pointed out by Dr. Dorey, still in the experimental stage. On the Continent there were Benson, La Mont, Loeffler, Sulzer, Wagner-Bauer and Velox boilers installed in ships and being given an opportunity of proving their worth. In this country, however, they had relatively little to show in the field of new development and the question must be asked as to whether operating companies generally were giving engineering progress and development that support which they ought to have. It was not only a question of their neighbours being a jump ahead of them, but they must also consider the resulting enrichment in knowledge, experience and outlook which was associated with such enterprise.

There was now a sufficient number of Velox steam generators in service over an extended period of operation to permit drawing some definite conclusions regarding its behaviour in service.

In a few instances individual tube failures had occurred and these were attributable, in practically all cases, to inadequate supervision of the boiler and feed-water condition. Their experience had shown that, while the evaporator elements were remarkably insensitive to feed and boiler water conditions, priming and carry-over, which might endanger the superheater tubes, must be guarded against. For satisfactory operation, therefore, a reasonably constant and close control of the feed-water condition was essential as with any other type of water-tube boiler. It might be mentioned here that it was not essential to operate with distilled water and there were, in fact, units operating on a 100 per cent. make-up. One of these, for example, in Roumania, was in service last year for a period of 11½ months without a single shut-down. A systematic investigation of the flow on the water side of the tubular evaporator elements had been carried out and this brought to light the fact that, in spite of the relatively high-pressure head driving the steam-water mixture through the tubes, there could be local areas where there was little or no flow or even a complete reversal of flow. For this reason, they now gave the water and steam a directed flow through the evaporator elements. If such conditions as described above could arise in a tubular element with forced circulation and a high mean velocity of flow, did it not suggest that natural circulation with its still more indeterminate flow could scarcely be used above moderate ratings without running into danger of tube failure.

They had thought originally that the relatively high gas speeds in the economiser would prevent condensation and, therefore, also corrosion. This had proved, however, not to be the case and the feed temperature must be kept above a certain minimum, which was about 180° F. if corrosion was to be avoided. Furthermore, in the design of the economiser, there must be freedom from pockets, etc., where carbon and ash might accumulate and promote condensation and subsequent attack on the materials.

In the early stages of the Velox boiler they experienced some trouble with the glands of the circulator pump, which had to operate at full boiler pressure and saturation temperature, and in certain instances repacking after a few days' operation was necessary. The difficulties were eliminated by providing, on the one hand, adequate cooling of the glands and, on the other hand, by designing the pump runner and casing in such a manner as to avoid transverse hydraulic forces, which might cause shaft whipping and wear in the glands. Actually the latest design of pump would operate satisfactorily for several thousand hours without repacking the glands.

With regard to the fuel oil, little difficulty had been experienced in burning satisfactorily almost any grade of commercial bunker oil, even though high rates of heat release up to 1,000,000 B.Th.U./cu. ft./hr. were employed, with the use of a single burner for all sizes of boilers up to 6-7 tons/hour of oil. In certain cases, however, accumulation of ash in the tubes had caused trouble as it necessitated a fairly frequent washing out of the boiler. They found that it was not necessarily the oil with the highest ash content which gave the maximum deposit, but rather that the sodium content or ratio of alkali sulphates to calcium and magnesium sulphates was the determining factor. The relatively high percentage of alkali salts in the residual oils came, of course, from the neutralising processes during refining, and consequently this investigation led inevitably to an examination of the possibilities of remedying the trouble at its source by modifying the refining methods with a view to leaving the residuals with an ash content less liable to form deposits in the tubes. This suggestion was, they understood, being followed up by certain refining companies on the Continent.

This question of ash deposit in the boiler was not in any way peculiar to the Velox, but was a major problem, particularly with certain naval type boilers, where the elimination of the deposits could not be easily effected as in the former class of steam generator, which lent itself to a simple sluicing out of the incrustation. It would be of interest if the author or anyone else could throw a little more light on this particular problem.

Apart from the foregoing difficulties, there had been a marked freedom from trouble. In particular, the mechanical equipment and automatic control had functioned extraordinarily well and in no part of the structure had there been any evidence of deterioration resulting from the high rates of heat absorption and quick temperature changes when starting rapidly from cold.

The "Athos II", which, as mentioned by the author, was recently fitted with a Velox boiler, returned on the 25th January from her first voyage after the refit. The Velox unit, which was used only when the vessel was steaming at full speed, was in service about 800 hours. At one period during the voyage, heavy condenser leakage led to priming and a bad patch of oil taken on board at Port Said necessitated relatively frequent washing out of the boiler in order to clear away the ash deposits. Apart from these two difficulties, they understood that the general operation of the installation was very satisfactory; they were, however, up to the present no figures available regarding fuel economy. By the end of the year complete service results over a reasonable period of time should be available.

Professor Wm. Kerr, Ph.D., wrote that while the author dealt with what were, in their main applications, high-pressure boilers, it might be contended that the proper designation should be high-rate boilers. Pressure, by itself, was not a seriously critical difficulty and, in any case, the author's very pertinent question "why do we want these very high pressures?" cast an element of doubt on the need to face the most serious difficulties in this respect. Some of the boilers described, like the Loeffler, were essentially high-pressure generators, but others, like the La Mont, were not necessarily so. Again, the developments that had taken place in the long-established forms of natural-circulation boilers made them quite fitted for high pressures. The distinctive difference, therefore, between the old and the new was not measured by pressure but by high flow, high heat release and high heat transmission rates. The sensational claims made for all these new boilers did not rest upon superiority in efficiency or for high-pressure generation, but ultimately on weight, space and control qualities that all derived from the high intensities of action incorporated in the designs.

As soon as this was realized, the reluctance of conservative engineers to become immediately enthusiastic could be appreciated. British marine engineering showed perhaps the most strongly marked reluctance. It could be understood. High intensity of action and reliability were not synonymous, and only perfect design could bring them together. The remarkable claims for these boilers were, in many respects, justifiable, and it must be admitted that the designs were highly impressive in their originality of conception and excellence of detail. But the vital matter of the life factor remained as yet undecided. The author in his presentation of service results did not give any indication of service troubles; but the disclosures that had been made at times of the earlier difficulties with high-pressure designs did not give a full assurance that service would be free from serious trouble, even although designs had now reached a higher standard.

The design standards had to ensure so much in these cases. The primary requirements were that the tubes should not be over-stressed into the creep field and that they should be fully safeguarded against scaling and overheating. The high heat rates and, in cases, the high wall temperature, made the former a delicate issue; while the notable use of small tubes and forced circulation did not, in spite of their many advantages, ensure the latter. There were also other problems associated with the reliability of the circulating elements and with the incidence of secondary stresses. It could hardly be said that the variety of designs described contained an example of security in all respects.

It was, however, in the heat transmission rates that these advanced boiler types were most notably distinguished. The stresses resulting therefrom would continue to create an element of doubt until long and safe service had shown that doubt to be unfounded. The author stated that in modern boilers, lined on all six sides with water walls, the heat absorbed by radiation ranged from 45 to 60 per cent. of the calorific value of the fuel. This presumably applied to normal boiler types and, if so, gave an extremely high value for the heat transmission rate in the furnace walls. With the known dimensions and heat release of a large water-tube boiler, and using 50 per cent. as a rough average of the author's values, the rate of heat transmission would appear as 100,000 B.Th.U. per sq. ft. per hour. This value was quoted by the author for the Velox boiler and probably applied thereto. It could not apply to the standard boiler type, otherwise there would be no meaning in the claims of the new and no merit in this respect in the conditions of the old.

There was actually a very great difference between the characteristic rates. The newer types were designed for values that must necessarily mean high heat stresses. Where, in addition, high wall temperatures and high pressures existed, the creep field was reached or within sight. The usual argument in connection with this was that cited by the author relative to creep relief. The stress considerations and the creep relief argument were based, respectively, on average conditions and uniformity of distribution. But in modern boiler construction and action, both were very far from the truth. A boiler furnace was a tunnel lining with a fire inside. There were stress variations along and around the tubes due to coil form and temperature. The flow of the gases and the incidence of radiation provided further causes of non-uniformity around the tube wall. Any sharp bends creating variations in wall thickness and any binding effects due to the end connections of the coil added to the conditions of non-uniformity. Wide variations in the water-steam ratio along the tube length, frequent load changes and the existence of any scale on the water side would all aggravate the conditions; and the tube stress system must be visualized as greatly different from the symmetrical, average and uniform distribution generally assumed. Creep development in any reasonable case might be slow, but as it developed it increased the non-uniform conditions and could not automatically give relief in a zone of intensified action due to secondary effects. It was the greater margin of security in this respect offered by lower rates that provided the essential features of contrast; and when viewed in conjunction with other severe actions in main and auxiliary elements the reasons why time alone could resolve the doubts should be appreciated.

The Author's Reply to the Discussion.

The author stated that he must first thank the members for the kind and enthusiastic way in which they had received the paper. It was gratifying to him as an author to find that so many were really interested in these modern types of boiler. He must also acknowledge his indebtedness to those who had taken part in the discussion. It was often stated that the success of a paper might be measured by the discussion it produced, but here he also felt that its value had been enormously increased by the information and criticism that had been contributed by so many of the speakers.

Before replying in detail to the discussion he felt that he ought to make his own position quite clear. He did not come as one who advocated the use of any particular type of steam generator. His duty had been rather to describe, as fairly as possible, the main features of the different boilers and to present in that description some clear idea of the fundamental principles underlying their designs. In this way it was felt that the members would have a reasonable assurance that the description had been presented without bias and that consequently some real appreciation could be obtained of the advantages and disadvantages associated with each boiler type.

The contribution of Dr. Dorey was most valuable, since he was recognized as one who must have a unique experience of boiler performance and yet could judge with an impartial eye the many examples which were continually passing through his hands. His question as to whether marine engineers would be prepared to fit one of the new type boilers in a one-boilered ship was most pertinent. The possible high rate of evaporation was the main feature of the boilers described and it would have been noted that a steam production per unit of 40,000 to 50,000lb. of steam per hour was looked upon as a very modest output. The ordinary vessel would therefore be assured of ample power with only one boiler, and consequently Dr. Dorey's question would have to be faced by all who contemplated using these modern boilers on new vessels. This question of reliability had been touched upon by the majority of the speakers: he felt that a careful reading of the evidence that had been presented in the paper would go a long way to help those who were considering the problem to make up their minds. With Dr. Dorey's observation upon the necessity for first-class tube material and for purity of feed water he was in entire agreement. In fact the importance of a pure feed had been specially stressed in the paper and all calculations dealing with heat transmission and the diagrams illustrating these calculations had been made upon the assumption that both gas and water sides of the heat transmission surface were in a clean condition. Beyond stating that nowhere in the paper had he made any such remark as "that he did not see the advantage of increased pressure" he would not deal at present with Dr. Dorey's point upon pressure. This was a question which had been raised by several speakers and it might be an advantage to consider all statements together rather than to make a series of isolated references to this important point.

The contribution of Mr. Roylands Cooper had added largely to the value of the paper and the Members of The Institute would be greatly pleased to have this additional information and also the illustrations of modern examples of the Benson boiler. He desired to thank Mr. Cooper very warmly for the trouble he had taken in this matter.

The long experience of Major Gregson with a firm of world-wide reputation gave great weight to any statement he made and consequently attention ought to be drawn to his assertion that "the idea that high water speed over the heating surface avoided scale deposition was not borne out in practice". Such a statement was quite opposed to the experiences of many who had knowledge of high speed water circulation and, in fact, several of the other speakers had testified to the efficacy of high water speed in preventing scale deposition. He would refer them especially to the experiences of the late *Prof. Nicolson during his tests of a high-speed boiler with small tubes using canal water. Major Gregson also pointed out that the highest boiler efficiency could only be obtained if the furnace gas temperatures were brought to the lowest practical limit, a statement with which everyone would agree. With the use of high pressures and stage feed heating the problem of obtaining low exit gas temperatures became one of some difficulty and could only be effected by the introduction of air preheaters. It did not, however, appear that there was any greater difficulty in applying such heaters to the new types of boilers than to the older designs, and in fact several of the boilers described in the paper had them as regular fittings. Along with several other speakers, Major Gregson had objected to the use of forced circulation but he considered that if very high rates of heat transmission were to be adopted, forced and controlled circulation were essential to safety. There was no doubt that many tube failures could be attributed to faulty circulation and tube bursts in some of the large modern boilers of standard design with their complicated system of water walls could definitely be put down to the failure of natural circulation. The satisfaction of Major Gregson with the standard types had reminded him of the discussion on Prof. Nicolson's paper, and indeed many of the criticisms made that evening were remarkably similar to those made at Glasgow nearly 30 years ago. The members might be interested if he quoted from Prof. Nicolson's reply to a statement made on that occasion by a member of the same firm as that with which Major Gregson was associated. "With regard to his further remarks practically asserting that nothing more economical of volume, of weight or of efficiency could be designed than the marine water-tube boiler of the present day that was a matter which it was useless to argue about. It must be left to the arbitrament of practical trial". Members who had followed the present paper and discussion would be able to form their own opinions upon what had resulted during the 30 years of knowledge of the possibilities of the high-speed boiler.

The remarks by Mr. Trevithick added to the information given about the La Mont boiler and were consequently welcome. Note should be taken of the statement that there were 500 such boilers either at work or on order and that of these 90 were for marine installations. The answers to some of the questions raised during the discussion upon possible saving of space were given in Mr. Trevithick's references to the boilers of the London Power Co. and to the special boiler illustrated in Fig. 21. It might also be noted that Mr. Trevithick's experience with scale deposition and high-speed water circulation was in agreement with the usually expressed opinion and contrary to the statement made by Major Gregson. With Mr. Trevithick's concluding remarks upon the advantages of forced circulation when high heat release and high heat transfer rates were desired the author was in entire agreement.

Mr. McEwen had some grounds for his objection to the use of "high pressure" in the title of the paper and no doubt, as other speakers had suggested, a better term might have been found in

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* "Boiler Economics and the Use of High Gas Speeds". Nicolson. Trans. Inst. of Engineers and Shipbuilders in Scotland, 1910.

"high duty". It would be agreed, however, that all of the boilers described, even those with pressures of 200 to 300lb./in.^{2}, were capable of being used under high or very high working conditions. Mr. McEwen was one of the few speakers who were definitely in favour of high pressure, a point to which reference would be made later. He rejected the idea that an interheater would be an added complication and quoted as an example the installation on the "Conte Rosso". Mention had been made in the paper of interheaters fitted by the North Eastern Marine Engineering Co. into vessels with reciprocating engines. All would be interested and pleased with his statement that the "Conte Rosso" had come with complete satisfaction through all her guarantee trials.

There were no points to which he need reply in Rear-Admiral Whayman's remarks, but he must thank him for his proposal that the paper had raised sufficient interest to justify an extra meeting for its discussion.

He had also to acknowledge his indebtedness to Dipl. Ing. Rudorff for the trouble he had taken to make such an extensive contribution to the discussion. Mr. Rudorff had put up a good case for the Schmidt-Hartmann boiler and it was indeed a creditable performance that the installation in the s.s. "Altair" had made during its unfortunate preliminary runs. It was of interest to note that repeat orders were being given, an indication at all events of satisfaction on the part of some steamship owners with boilers away from the ordinary design. The figure relating to heat transfer coefficients with steam-water mixtures was of value and would go along with that prepared by Mr. Harley-Mason. He was interested in the other details relating to water circulation velocity and especially in the remark that the velocity of the steam-water mixture in the tubes had no influence upon the magnitude of the coefficient. This was in agreement with the experiences of *Nicolson and Royds, both of whom had found that once the water was moving at something of the order of 1ft. per second, further increase of speed did little to increase its heat absorption rate.

The contribution of Mr. A. W. Richardson did not call for any special remarks. Although the high heat release values quoted by him might be developed on occasion, there was no doubt that the ratings given in the paper for modern power stations using pulverized fuel were substantially correct.

The controversial and important question of stress relief was raised by Mr. Forsyth, and in reply little could be added to what had already been given. It seemed fairly evident that the stresses as calculated both for the pressure and heat transmission effects would first be developed in the tubes. It was also certain that there would be some stress relief from creep in the material, but due to the time necessary for creep to take place this stress relief would be very slow and probably would not go very far. It seemed therefore that the intermediate condition favoured by Mr. Forsyth would represent the actual state of affairs. With Mr. Forsyth's statement concerning the stress condition when cold the author was in agreement.

He was indebted to Mr. Harley-Mason for the diagram he had produced dealing with the characteristics of a water-steam mixture during evaporation. The general impression it gave was that the water must adhere closely to the tube walls until almost all of it was evaporated and that, as had been predicted in the paper, with a forced circulation there was little fear of tube overheating. But contact between water and the heated walls was essential for safety. Experience had shown that, with bent tubes in a combustion chamber, failure was almost certain under intense combustion when the curvature was such as to throw the water away from the hottest sides of the tube.

The author was glad to have occasioned a contribution from one of the younger members, Mr. Marriner, the son of one who was known all over the world for the work he had done on boiler development. Mr. Marriner appeared to be inclined to believe that because an order had been given for a particular type of boiler therefore that boiler was the best. But it was well known that in another power station in England a large installation using Loeffler boilers at a pressure approaching 1,900lb./in.^{2} was nearing completion, and Mr. Trevithick had just informed them that in another station a large boiler of the La Mont type had been ordered. Which of the responsible engineers had the greatest wisdom was a question the author did not feel disposed to answer. Perhaps, however, the best reply he could make to criticism such as this was to give another quotation from the discussion on Nicolson's paper and allow Mr. Marriner to judge how far the ideas there expressed could be applied to present-day conditions. "Dr. Nicolson pictured an installation of his boiler on such a ship as the 'Lusitania'. He had not the pleasure of the acquaintance of the designer of the boiler arrangements of that ship, but he had not the smallest doubt that that gentleman knew all about Belleville, Thornycroft, Babcock & Wilcox and other boilers that had, more or less, been tried afloat and had advisedly discarded the idea of using such". It must not be supposed that oil fuel was essential to the boilers that had been described. With the possible exception of the Velox boiler, all others were adopted for coal firing and he had seen examples of Loeffler boilers using both pulverized coal and mechanical stokers.

The contribution of Mr. Blenkinsop was complementary to that of Mr. McEwen and gave the details of the trials made on the "Conte Rosso".

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* "Possibilities of Flue Gas Economisers on Board Ship". Royds & Campbell. Trans. Inst. Eng. and Shipbuilders in Scotland, 1912.

This would satisfy the wishes that had been expressed for service results and he was sure that all would agree that the performances of the Loeffler boiler and the h.p. turbine installation were most satisfactory. They were much indebted to Mr. Blenkinsop for the information he had placed at their disposal.

With many of the statements made by Mr. Reid the author was unable to agree. His claim for the high heat transmission rates in the Scotch boiler was remarkable, but if it were correct the evaporative capacity of such boilers would be many times greater than that commonly attributed to them. The so-called formula for the radiant heat emission was merely intended to show how greatly it depended upon the furnace temperature T. Contrary to Mr. Reid's statement, the determination of the temperatures T and θ was comparatively simple and would be calculated beforehand by a competent boiler designer. Figs. 3 and 4 were made from photographs taken at Clydebank, but for the further criticism made upon the furnace arrangement members were referred to the answers given by Mr. Harley-Mason.

With practically all the statements made by Rear-Admiral Parnall he was in entire agreement. He had regretted in the paper the difficulty of obtaining relative weights and volumes but thought that some contribution to their knowledge upon these points had been made during the discussion. Obviously boiler economy was closely associated with both mass and volume and consequently unless all boilers compared had similar fittings, such as economisers and air heaters, deductions made were likely to be misleading. At the same time he thought that in all the boilers considered, with the exception of the Velox, there were further possibilities of weight reduction by the use of higher controlled gas speeds in superheaters, economisers and air heaters.

He could sympathise with Mr. Paterson in his desire to know more about the working conditions in these new boilers, but unfortunately he was unable to give him much assistance. Still, he thought that Mr. Paterson would obtain some relief by considering Admiral Parnall's opening remarks. It did, however, appear clear that, especially in the examples working under severe pressure and temperature conditions, pure feed water was essential for trouble-free working.

Some of the points raised by Mr. Stephenson had been already answered by other speakers. His question on heat transmission could best be answered by referring to Fig. 1. The diagram showed how much more difficult it was for the hot gases to put heat into the plate and for the superheated steam to extract heat from the plate than it was to pass heat through the plate. Thus the resistance to the heat entering the plate could be taken as proportional to $T-\theta_1$ and that to the heat passing through as proportional to $\theta_1-\theta_2$.

Mr. Payne presented an interesting contribution which showed that he appreciated where possible troubles might arise with some of the boilers illustrated. He was grateful to Mr. Payne for reminding them that even the Scotch boiler was liable to occasional failures. He understood, however, that in the Velox boilers no difficulties in service were experienced as suggested by Mr. Payne. In most of the boilers described welding was largely employed, and from the remarks of Dr. Dorey it would be gathered that this method of construction was proving very reliable. For connecting the lengths of the small diameter tubes gas rather than electric welding was largely used, and it must be granted that on the Continent they appeared to be well ahead of us in this method of boiler construction. The circulating pumps used in some of the boilers also appeared to be free from troubles, and as had been pointed out on several occasions by the manufacturers, no great disaster was inevitable if they did fail. The corrosion in economiser tubes when they were first employed in marine service was almost entirely due to the slow circulation of both gases and water.

With regard to Mr. Revill's question on water gauges, he would refer him to a description of the Siemens water level indicator, as used in the Loeffler drum, contained in the paper on "The Loeffler Boiler Installation of the s.s. 'Conte Rosso'" given by Mr. McEwen to The Institute in March, 1937. In addition to this indicator an ordinary water gauge was fitted for use while the water level in the drum was being adjusted and before the maximum pressure was obtained. This auxiliary gauge was, however, shut off during working conditions. He had seen the Siemens indicator in operation on a number of boilers and was assured by those in charge that it was very reliable. It would he thought be recognized that in the Loeffler drum the rise or fall of a few inches was of little moment.

He was glad to have a contribution from so experienced and well-known an engineer as Mr. Hamilton Gibson. The question of cleaning the heating surfaces had been raised by several of the speakers as well as by contributors to the engineering press. Personally, he was unable to see that the achievement of cleanliness was such a difficult problem, and as all the boilers described were working satisfactorily in different parts of the world he assumed that it had been solved by the individual boiler makers. Certainly in those boilers which he had inspected, tube cleaning was carried out regularly and efficiently. He felt that a great deal of the soot deposit nuisance could be avoided by controlled and rapid circulation of the furnace gases. That was the experience of Nicolson, who found that, with gas speeds in the region of 100ft. per second, a thin film of carbon was formed on the tubes within the first few hours and after that remained permanently without thickening. He had already referred to the external and internal corrosion experienced in the very early applications of the economiser to marine service, due to sluggish gas and water circulation.

Some useful information on tube material properties was presented by Mr. Adamson, and he felt indebted to him for these figures. In view of the remarks of previous speakers, his statements on scale formation ought to be noted.

Since the Velox boiler was one of the most revolutionary of those described, the communication of Mr. Dean would be read with great interest. They were indebted to him for the details of performance he had given and especially for his frank remarks upon early failures. All would be pleased to learn that the early runs of the s.s. "Athos II" were satisfactory and they would look forward to the publication of the service consumption and power figures.

He welcomed the contribution from his former colleague Professor Kerr, and recommended its careful study to the members. The case for the new boilers was very fairly put and the dangers that might arise from the heat transmission stresses when added to the pressure stresses were clearly indicated. The necessity for correct design was emphasized, but it might be conceded that one of the features associated with the new steam generators was that the design problems had been faced in a thoroughly scientific manner. He had been gratified to see into what elaborate details of stress estimating some of the new school of designers went. Still, it could hardly be said that the increased heat transmission rate proposals were new. It was 64 years ago that Osborne Reynolds put forward the theory and the laboratory experiments supporting it, indicating how heat transmission rate could be so greatly increased by high gas speeds. It was nearly 30 years ago since Nicolson showed the correctness of Reynold's observations by tests on a full-sized boiler. During the war he himself, along with one of the most distinguished engineers on the Clyde, had attempted to interest the Admiralty in high-speed high-duty boilers, but no success attended their efforts. Since then Continental engineers had taken up the work and there was no doubt that they had produced boilers which would work successfully under extraordinarily high ratings.

Before concluding, the author felt that some reference ought to be made to the pressure problem. There could be no doubt about its importance and he had been astonished to notice how, in some cases, plants working under extreme conditions had been ordered without, so far as he could see, any reason for their adoption. The only justification for the use of very high pressures would be the certainty that, under such conditions, really worthwhile increases in economy would be obtained. It was to discover whether any member could put forth a reasonable theory to justify such an expectation that he had put the query towards the end of the paper. In considering the remarks of those who had responded to the question, it would be found that only Mr. McEwen was an out-and-out supporter of the high-pressure installation. He was unable to understand Mr. McEwen's statement about the diminished rejection of latent heat since the heat rejected to the condenser was determined by the limiting wetness condition of the steam at exhaust. Some suggestions were made about stage feed heating, but this process had little relation to pressure. The younger members of The Institute would be interested to learn that stage feed heating was first introduced over 40 years ago by the late Mr. James Weir—one of the founders of Messrs. G. & J. Weir, Ltd., of Cathcart—for marine engines and boilers. It would be recognized that at that time pressures in the marine service were comparatively low.

Of the other speakers Dr. Dorey did not commit himself, but he indicated that the general tendency seemed to keep to moderate pressures of the order of 500 to 700lb./in.^{2} The opinion of Major Gregson was that there was little nett gain in exceeding 500lb./in.^{2} Mr. Trevithick, largely to avoid interheating, considered that the best pressure lay between 600 and 850lb./in.^{2} and Rear-Admiral Parnall appeared to support the suggestion of Mr. Cook that 750lb./in.^{2} was the reasonable limit. Several speakers had proposed that the author should express his own opinions, and he therefore had no hesitation in stating that he was on the side of those who advocated the use of the more moderate pressures. It was a subject to which he had given a great deal of attention and to those who cared to study it in detail he suggested a study of two *papers written in collaboration with Professor Kerr and a recently published †article he had also prepared. Without going into details he thought it to be quite certain that beyond 750lb./in.^{2} the gains to be expected by pressure increase were very small. Thus, in accordance with the figures that were presented in the papers, between 750 and 1,000lb./in.^{2} the possible gain in efficiency was only 1 per cent. and by rising to 2,000lb./in.^{2} a further 1 per cent. might be obtained. In these calculations all the advantage to be gained from interheating and stage feed heating had been taken into account.

In conclusion, he might say that the criticisms applied to the new boilers were similar to those made of every new proposal, especially in marine engineering. In his own experience he had seen the development of the steam turbine and the internal-combustion engine. Let them think of the outcry against the introduction of the steam turbine for

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* "The Limiting Possibilities of Steam Plants". Trans. N.E.C. Inst. E. & S., 1925, Vol. XLI, and "The Use and Economy of High Pressure Steam Plants". Proc. Inst. Mech. E., 1927.

† "Power and Works Engineer", Jan., 1938.

ship driving and of the still more fierce opposition to the introduction of the internal-combustion engine. Note also that nearly all the disasters predicted had occurred at one time or other. Steam turbines had stripped their blades and ruined their gears, internal-combustion engines had experienced cracked pistons and liners, and burnt exhaust valves. But notwithstanding these failures no-one would advocate the general return to the triple-expansion engine or the earlier boiler pressures of 5 to 10lb./in.^{2}

The truth was that they were terrified of the unknown and exaggerated the possibilities of the dangers they might incur by departing from the well-trodden paths. When once they had accepted the new conditions and accidents and difficulties did occur, they accepted them as a matter of course and overcame them with the minimum of excitement. So it would be with the new types of boiler. Only let them see, when they were accepted as standard practice, that the pioneers received due credit for their foresight and courage.

INSTITUTE NOTES.

ELECTION OF MEMBERS.

List of members elected at Council Meeting held on Monday, 4th April, 1938.

Members.

Richard Boyes, Jun'r., 120, Dove House Lane, Solihill, Birmingham.

William Moreland Campbell, 7, Woodend Drive, Jordanhill, Glasgow, W.3.

Francis John Colvill, Fairview, Moor Lane, Rickmansworth, Herts.

Frank Evans, Lythcote, Meole Crescent, Shrewsbury, Shropshire.

Robert Millar Logan, 2222, Alma Road, Vancouver, B.C.

Reginald John Shearn MacPherson, 70, Amesbury Road, Cardiff.

Leslie Taylor Morton, B.Sc., Lyndhurst, Three Mile Bridge, Gosforth, Newcastle-on-Tyne, 3.

Edward Philip Paxman, M.A., 12, St. Clare Road, Colchester, Essex.

Joseph William Regan, 7, Moseley Mansions, Moore Road, Durban, South Africa.

John Brown Smithson, 60, Borough Road, Redcar, Yorks.

Arthur Closson Widgery, 19, Marlborough Lane, Charlton, S.E.7.

Companion.

Gianni Procacci, 15, Rue de Clery, Paris, France.

Associates.

Joseph Robertson Craig, 586, Holburn Street, Aberdeen.

Kenneth Leonard Ernest Jarvis, No. 11 Eleventh Av., Inglewood, West Australia.

William Langford Kerr, 109, Northwood Street, West Leederville, Western Australia.

Archibald Paterson McCormick, 33, Tynwald Hill, Liverpool, 13.

Patrick Flower Whyte, Ratmewella, Kadugannawa, Ceylon.

Transfer from Student to Associate.

Raymond Belcher, c/o C.S. "Norseman", Western Telegraph Co., Caixa 453, Rio de Janeiro.

John Charles Robert Sundercombe, 5, William Street, North Brighton S5, Victoria, Australia.

ADDITIONS TO THE LIBRARY.

Purchased.

Reports of the Progress of Applied Chemistry, Vol. XXII, 1937. Published by Society of Chemical Industry, 12s. 6d. net, and containing the following :—

"General, Plant, and Machinery", by Donald and Thorp.
"Fuel", by King.
"Gas, Destructive Distillation, Tar and Tar Products", by Hollings and Voss.
"Mineral Oils", by Goulson.
"Intermediates and Colouring Matters", by Rodd, Holmes, Irving, Lapworth and Thomson.
"Fibres, Textiles, and Cellulose", by Speakman, Whewell and Turner.
"Pulp and Paper", by Edge.
"Acids, Alkalis, Salts, etc.", by Prince and Wilkins.
"Glass", by Cousen.
"Refractories, Ceramics, and Cement", by Sugden.
"Iron and Steel", by Bannister.
"Non-ferrous Metals", by Powell.
"Electrochemical and Electrometallurgical Industries", by Cuthbertson.
"Oils, Fats, and Waxes", by Hilditch.
"Paints, Pigments, Varnishes, Resins, and Solvents", by Members of the Oil and Colour Chemists' Association.
"Rubber", by Garner.
"Leather and Glue", by Burton.
"Soils and Fertilisers", by Crowther.
"Sugars and Starches", by Eynon and Lane.
"The Fermentation Industries", by Hopkins, Norris and Preece.
"Foods", by Moran and Smith.
"Fine Chemicals and Medicinal Substances", by Stedman.
"Photographic Materials and Processes", by Horton.
"Sanitation, Water Purification, etc.", by Coste.

The Yearbook of the Universities of the Empire. The Universities Bureau of the British Empire, 15s. 6d. net.

Presented by the Publishers.

Register of Ships, 1938. The British Corporation Register of Shipping and Aircraft.

Supercharging of the Compression-ignition Engine for Road Vehicles. By Pomeroy. Diesel Engine Users Association.

The Ford 8 h.p. Chassis (Instructions for Dismantling and Assembly). Ford Motor Co., Ltd.

Proceedings of the General Discussion on Lubrication and Lubricants, Vols. I and II. The Institution of Mechanical Engineers.

Additions to the Library.

The following publications of the Combustion Appliance Makers Association:—

Report of the Research Council for the year ended 30th November, 1937.
Bulletin of the Research Department, Vol. II, No. 2.

The following British Standard Specifications:—

No. 321, 1938. General Grey Iron Castings, Grades A and C.
No. 779, 1938. Cast Iron Boilers for Central Heating and Hot Water Supply.
No. 780, 1938. Riveted Steel Boilers for Hot Water Central Heating and Hot Water Supply.
No. 786, 1938. High Duty Iron Castings, Grades 1, 2 and 3.
No. 787, 1938. Flame-proof Air-Break Electrically-Operated Gate-end Boxes.
No. 788, 1938. Wrought Iron Tubes and Tubulars, Gas (light), Water (medium) and Steam (heavy) Qualities.
No. 789, 1938. Steel Tubes and Tubulars, Gas (light), Water (medium) and Steam (heavy) Qualities.

(The attention of members is called specially to the the two last-named standards. Both provide for the qualities known in the trade as "gas", "water", and "steam". Whilst primarily drafted to cover screwed and socketed tubes, the requirements are, in general, equally applicable to plain end tubes. Both specifications are comprehensive and include requirements relating to quality of material and workmanship, test pressures, galvanising, tolerances, marking and packing for transport. The range of sizes covered is from ¼ to 6 inch nominal bore and complete tables of dimensions and weights are given for both tubes and sockets. The specification also includes requirements and tables of dimensions for tubulars, i.e., pieces, long screws and back-nuts, bends and springs and barrel nipples. Copies can be obtained from the Institution, price 2s. each or 2s. 2d. post free. For quantity orders special discounts are available.)

Transactions of the Institution of Engineers-in-Charge, 1936-37, containing the following papers:—

"Corrosion and Modern Methods of Preventing Same", by Swindin.
"Progress in Electric Lamps and Lighting", by Jones.
"Factory Lighting and Accident Prevention", by Murray.
"Television", by Marris.
"Some Problems of the Heavy Oil Engine", by Wans.
"American Methods of Heating and Ventilation", by Benham.
"Gas Service", by Le Fevre.
"Small Unit Refrigeration—Gas and Oil", by Young.
"The Modern Steam Trap and Its Application", by Brown.

Engineering Workshop Manual. By E. Pull. The Technical Press, Ltd., 6th edn., 182 pp., 140 illus., 3s. 6d. net.

The object of this book, now in its sixth edition, is to provide in as small a space as possible practical information that should be known by all apprentices, improvers and journeymen engaged in engineering workshops. It frequently happens that the book giving the desired information is not available at the moment it is required, or the data is difficult to find. A book of this size can be conveniently carried in the pocket, and is likely to be at hand when wanted. In this new edition the various chapters have been revised, and the information will be found up-to-date and reliable.

Mechanics for Engineering Students. By G. W. Bird, Wh.Ex., B.Sc. Sir Isaac Pitman & Sons, Ltd., 3rd edn., 158 pp., 111 illus., 5s. net.

In the study of mechanics, engineering students soon realise that it is one thing learning principles and quite another in being able readily to apply these principles to practical, everyday problems. In his book the author has given a wealth of worked examples which are well set out, and which will greatly assist the student in working the additional problems at the end of each chapter.

As stated in the preface, the subject matter has been compiled for the benefit of third-year students taking the examination for the National Certificate in Mechanical Engineering and similar examinations. For the student working privately at home it is an invaluable little text book. In the space allowed, stress and strain is very thoroughly dealt with and the chapters on graphic statics and beams are particularly good. As every engineer knows, the use of graphical methods is fully justified in most engineering problems, the results obtained usually being as accurate as the data warrants. Dynamics and hydraulics are very adequately dealt with to suit the needs of the young engineer and here again the practical character of the worked examples adds to their value.

Commensurate with its size, this book is a clear and concise work and will be of value not only to the student working for examinations, but to the engineer who may occasionally require to fresh his memory on some point in mechanics.

Vibration Problems in Engineering. By S. Timoshenko. Constable & Co., Ltd., 2nd edn., 470 pp., 229 illus., 24s. net.

The author of this volume has set himself an impossible task, having tried to cover in one short volume a field of knowledge which, if properly dealt with, would require many times the space that he has allowed himself. That the author is thoroughly conversant with the theory of vibration, there can be no doubt. Had he confined his efforts to a full treatment of the theory he would have given us a work of the utmost value, for there is at present no book published which deals comprehensively with this subject.

In the practical application of theory the author does not seem to be so happy. A few examples may serve to illustrate this. On page 17 it is shown that "beating" may occur in a simple system subject to a single vibrating force. One must assume that the author is correct in his mathematical proof of this, but even if this is so the phenomena is not observed in practical tests; yet in the book it is stated that it may be of practical importance. On page 29 the extra load on the rail caused by vibration due to unbalance in locomotive wheels is calculated on the totally erroneous assumption that rail flexibility is constant along the length of a line, i.e. that it is continuously supported, and not carried on sleepers. The treatment on page 107 of the effect of a low spot on a rail is equally impractical for the same reason. On page 141 in the chapter dealing with systems having non-linear characteristics the idea is given that the amplitude curve is not continuous, but is made up of three distinct sections. The further explanation clears this up but the wording on the page referred to is such that it may leave a false impression. In dealing with varying pressure of a motor car wheel on the road the effect of elasticity of tyres is neglected and the bumps are assumed to have a smooth even contour. In this section on page 239 it is stated that "pressure is a maximum when the wheel occupies the lowest position on the contour", which is only true when in addition to the stated assumptions there is no damping and the car is running below a certain definite speed. It will be seen that the treatment of this problem is based on assumptions such that the results are of no practical value. The question of gearing in a torsional vibration system is dismissed in less than two pages. The effect of errors in cutting of the gears and other important problems of a geared system, are not mentioned. The effect of the forces from the various cylinders of a reciprocating engine is very inadequately treated on page 269 and there does not appear throughout the volume a proper treatment of a system in which vibrating forces are applied simultaneously at a number of points in the system. The useful practical problem of ship hull vibration is dismissed in four pages, while impact vibration on uniform bars is given thirteen pages, and the vibration of membranes and plates (of uniform thickness and shape) takes no less than twenty-four pages. Following the latter, turbine discs are briefly considered in six pages.

These examples of the weakness of the author's treatment of practical problems have been made fairly extensive to warn the student of the work against applying the author's arguments without first carefully considering the assumptions he has made and whether his treatment of any particular problem is adequate.

Where the author treats purely the theoretical side of the subject his work is excellent, and provided that the reader considers the book as a grounding in theory and makes his own use of this theory in its practical application then it may be strongly recommended.

As a work of reference the value of the book would be increased by the addition of a table giving the use to which various letters and terms are put. Also for use as reference a much more extensive index is required. A thorough editing of the volume has been overlooked. In the table of contents one of the headings given does not appear at all in the book, and another heading is wrongly paged. Cross references are not all correct—for example on page 111 the reference to Fig. 36 should be to Fig. 37. The subject index contains a number of errors, in some cases the wrong page is given, in others the subject indexed does not seem to be mentioned at all.

The author's references to other authorities are exceptionally complete and form a most useful feature of great value to anyone who wishes to study thoroughly any particular problem in vibration.

Generally, this volume can be recommended to students whose mathematics is up to degree standard, and who have a sound general knowledge of engineering.

The Theory and Performance of Axial-flow Fans. By C. Keller. McGraw-Hill Publishing Co., Ltd., 140 pp., 112 illus., 24s. net.

This book represents a careful selection and condensation by Professor Lionel S. Marks of the information contained in Dr. Keller's 185-page German treatise "Axial Fans from the Standpoint of Aerofoil Theory", published at Zurich in 1934. Dr. Keller is chief engineer of the Escher Wyss Laboratories at Zurich and, having exceptional opportunities for theoretical and experimental studies of the nature indicated by the above translated title of the original treatise, he has produced a comprehensive treatment of the subject from the particular viewpoint adopted. By courtesy of Dr. Keller, the writer of this review received a copy of the treatise before its publication in English, and can thus appreciate the skill of Professor Marks in selecting and presenting the salient contents in our language.

A very interesting feature of the volume is that Dr. Keller, being in a position to regard the subject from the viewpoint of an investigator dealing with both aeronautical and water-turbine work, has used an adaptation of the water-turbine engineer's criterion (specific speed) to correlate the factors of aerofoil theory applicable to fan design. Specific speed can be defined as a means for comparing, upon a uniform basis, the performance of different rotary impeller machines. For a water turbine it is the speed in revolutions per minute at which a suitable exact scale model of the turbine would develop one unit of power with one unit of head, whilst for a rotary impeller pump of the centrifugal or of the screw type, it is the speed in revolutions per minute at which a suitable exact scale model of the pump would deliver one unit of volume with one unit of total head. Dr. Keller has shown that a similar conception can be applied to develop the design and to interpret the experimental results of axial-flow fans, and whilst this appears new ground to most marine engineers it merits appreciation and respect.

From the marine engineer's point of view however, it is regrettable that as technical information concerning screw-type water turbines, modern air-screws, and axial-flow fans, has hitherto been published almost entirely by engineers not connected with the older art of marine screw propeller design, certain accepted terms, such as pitch, have been given other meanings than those understood in marine practice.

In Professor Marks' selective translation Chapter 1 deals with the application of fundamental and of aerofoil theory to single-stage axial-flow fans, with directing or guide vanes situated alternatively *before* or *behind* the rotor, and proceeds to a discussion on the variation of performance with operating conditions and of the incidence of efficiency and of energy losses. This chapter contains 67 equations, expressed in terms of the symbols defined before the opening of the chapter, also numerous curve diagrams and an efficiency table.

Chapter 2 opens with the development of the characteristic number (expressed by the Greek letter sigma), which number is analogous to the specific speed of the turbine designer; it then carries this up to an equation which indicates 129·5 times the characteristic number obtained for fans as representing the corresponding specific speed for pumps. The chapter continues with a determination of fan losses in terms of the characteristic number, and following this describes the determination of the principal dimensions for a fan, ending by a consideration of the conditions obtaining at the hub and at the blade tips.

Chapter 3 considers the action of various blade sections or profiles in retarded flow, namely, in flow against an imposed pressure or resistance, first for an individual section, then for several sections in grid and in cascade or echelon arrangement, this being taken as representative of the successive sections of blades in a fan when cut by a cylinder having the same axis as the fan. Interesting comparative diagrams are included to show the difference in pressure distribution over the face and back of the blade section chosen, both when tested alone and when tested in a cascade grid setting containing several of these sections. The necessity for guarding against disturbance of the air on the inflow side, when several sections are involved as in a grid or in a corresponding fan, is stressed in this chapter.

Chapter 4 describes the test installation used by Dr. Keller and gives a detailed account of tests on four fans having blades ranging from four to twenty in number and with hubs ranging in diameter from 33 per cent. to 70 per cent. of the rotor diameter. Curves showing the characteristics of performance and the efficiencies for uniform speed conditions with various settings of the blades, are plotted for the various fans tested, whilst these characteristics are discussed, together with the effect of varying the number of blades in a fan. The chapter, and the book, closes with an investigation of the flow conditions adjacent to the fan rotor.

This book represents a very complete treatment of the axial-flow fan from the standpoint at present adopted by the majority of designers and, although this is not necessarily the only standpoint, the book constitutes a valuable addition to the literature of the subject.

Diesel Operators' Manual. By J. W. Anderson. McGraw-Hill Publishing Co., Ltd., 263 pp., illus., 15s. net.

The author of this book has undoubtedly achieved that which he set out to do, namely, to supplement, rather than replace, the usual engine builders' manual. By his clear and comprehensive treatment of his subject, he has provided a treatise which, apart from proving a useful adjunct to the technical library of the fully-trained engineer, cannot fail to be of particular assistance to the many operators who are in charge of Diesel-driven units that are being used in increasing numbers for marine and industrial purposes.

The book deals in an exhaustive and concise manner with every phase of Diesel operating and maintenance, its value being enhanced by the author's emphasis throughout of the supreme need on the part of the operator of a thorough understanding of all that goes on in any Diesel engine. Stressing the importance of checking shaft alignment, exhaust cooling and lubricating systems, he follows on with a discussion of the essential details which must receive attention in order to ensure maximum efficiency and economy. The reader is fortunate in being given the benefit of the author's twenty-five years' experience in the Diesel engine industry, as well as of his discussions with various underwriters' engineers and expert engine operators.

Although this work is based mainly on the author's experience in U.S.A. in connection with land type engines, it should prove invaluable to all responsible for the running and maintenance of small and medium powered Diesel machinery, whether of the marine or stationary type.

Fundamentals of Machine Design. By C. A. Norman, E. S. Ault and I. F. Zarobsky. Macmillan & Co., 486 pp., 417 illus., 18s. net.

This book is Messrs. Macmillan's latest addition to their well-known "Engineering Science Series" and they and the authors are to be congratulated on the production of an excellent work. Each of the authors is an educationalist, Messrs. Norman and Ault being Professors of Machine Design at the Ohio and Purdue State Universities respectively, whilst Zarobsky is Professor of Mechanical Engineering at the University of Toledo.

It is stated in the preface that emphasis has been placed on the "fundamentals of machine design" as well as on the application of those fundamentals to the design of machine elements; this the authors have done with exceptional care, with the result that they have produced a book of immense value to both the student and the practising designer. Especially noteworthy are the chapters on engineering materials, remarkable not only for the extent of the range of materials described but also for four pages of notes on stress concentration and working stresses at ordinary and elevated temperatures that should give many designers fresh food for thought. Much attention is given to methods of transmitting power, joints and jointing methods and a special chapter is devoted to the problems arising from vibratory stresses. At the end of each chapter is given a number of questions, all of which have been carefully framed to cover the teaching imparted.

The book should have a good reception, especially by students who should remember, however, that British and American practices do not always coincide, especially in regard to riveted joints and pressure vessel construction, and in such problems of design reference should be made to British Standards.

Small Internal Combustion Engines. By E. T. Westbury. Percival Marshall & Co., Ltd., 133 pp., 43 illus., 2s. 6d. net.

This book has been written with the object of being of assistance to the non-technical user or prospective user of small petrol and petrol-paraffin engines having outputs up to a maximum of 2½ b.h.p. No attempt has been made to go into details of design of these engines or that of their individual components but sufficient information has been given for the reader to understand the working of the engines.

The first three chapters deal very briefly with the uses, running costs, types of engines, working principles and relative efficiencies, whilst the two following chapters describe ignition, carburation, governing, silencing, etc., in a brief non-technical manner. Included are descriptions of modern magnetos, coil ignition, low-tension ignition and various forms of modern carburettors suitable for stationary engines. Chapter VII is of interest as it gives useful information on the installation, running attention, maintenance and repairs of these small stationary engines. Some various makes of engines now available are described in the next chapter. Adapting engines of the motor-cycle type for stationary purposes forms a useful subject in chapter IX, in which many points are discussed which may be overlooked by a non-technical person. Special applications of small internal-combustion engines in stationary work and in portable units are discussed in a few paragraphs in the following chapter, whilst the concluding chapter deals with the most common troubles that are experienced in running and their remedies.

The book is well illustrated and it will be found interesting and instructive to those who require a knowledge of these small engines.

Motor Boats. By William Atkin. Macmillan & Co., Ltd., 149 pp., copiously illus., 10s. 6d. net.

The author of this book has been described by Mr. C. F. Chapman, the editor of "Motor Boating", as America's foremost designer of small yachts. Somewhat naturally this book deals exclusively with American practice, especially regarding construction. The designs given represent round bottom, vee bottom and flat bottom type boats of less than 40ft. overall length, and all those published have proven satisfactory. Mr. Atkin envisages types suitable for various cruising waters—inland lakes, rivers and open sea—and emphasizes the importance of what he calls a "neighborhood boat" or one produced and developed for some particular place. We are informed that he has always made it a practice to develop a new design from an existing one from which a boat has been built, so that the element of chance as it applies to performance has been eliminated. Mr. Atkin's dictum that only by building boats, having boats built and going out in boats can experience be got is true enough, but he could have added begets confidence, which is equally important.

A noticeable feature between American and British practice in the craft represented relates to the powering of such boats. A typical example may be quoted: on page 38 "Lance", a lovely round bottom 22-ft. overall open launch for day cruising, is recommended to be fitted with a 30 h.p. unit giving a speed of 16 to 18 m.p.h., and this is described as a medium-speed motor-boat; under prevailing conditions in our estuaries such a speed in a 22-ft. boat would involve relatively high running costs and a great deal of discomfort for those on board, even though the cockpit forward is protected by shelter housing. Details of dinghies—a trio—that have been tried and proven are also included.

This book can be recommended to and will be appreciated by those interested in the grand sport of motor boating.

JUNIOR SECTION.

Grit Collecting and Treatment of Flue Gases.

A very instructive lecture was delivered under the above title by Mr. Crawford W. Hume at a joint meeting of the Junior Section and the Students of the Sir John Cass Technical Institute, Aldgate, on Thursday, 17th March, 1938. Mr. F. H. Reid, B.Sc., Wh.Ex. (Member of Council) deputized in the Chair for the Principal of the College who was indisposed. Mr. Hume gave an exhaustive general survey of the subject from the land as well as the marine side, to both of which aspects his firm has devoted a great deal of attention. A large number of slides of modern land and marine plants was a valuable supplementary feature of the lecture, a fuller report of which it is hoped it will be possible to publish in a future issue of the Transactions. On the proposal of the Chairman Mr. Hume was heartily accorded a vote of thanks for his excellent lecture, while the Chairman himself was warmly thanked for so ably deputizing for the Principal.

ABSTRACTS OF THE TECHNICAL PRESS.

International Rules for Marine Electrical Installations.

The writer traces out the course of the international conferences which, during the last four years, have been engaged in framing rules relating to the construction and materials employed in marine electrical installations, and he gives particulars of the recommendations put forward by those of the sub-committees which have completed their reports. The first of these conferences, which was held at The Hague in January, 1934, was called by the Dutch Engineering Standards Committee in order to discuss a report setting out the advantages and disadvantages of single and double pole installations, differences of opinion as to their respective value in reducing the fire risk at sea having led to the prohibition of single pole installations in several countries, while preference was given to them in others. In addition, a report on automatic switches was laid before the conference, which after a full discussion unanimously recommended that the London International Electrotechnical Commission (I.E.C.) be requested to organize an international investigation. At its September meeting at Prague the I.E.C. accordingly set up a commission for the study of the problems involved. Its inaugural meeting was in June, 1935, at Scheveningen, where a programme was drafted and the work divided out among eight sub-committees dealing respectively with (1) nomenclature and definitions, (2) editing of reports, (3) electric propulsion, (4) cables and conductors, (5) generators and motors, (6) distribution, (7) tank vessels, and (8) sundry installations, viz.: low tension, wireless, signalling, lightning protection and general rules for testing and survey. One year later a considerable portion of the work was sufficiently far advanced to be submitted for discussion at a meeting in London where the sub-committees dealing with propulsion, motors and generators, tank vessels, and sundry installations presented their complete reports. These, however, required some subsequent co-ordination to eliminate discrepancies in the recommendations on certain points which had been dealt with independently by more than one of the sub-committees. As an example of such differences the writer quotes the treatment of the problem of ensuring the safe functioning of electric and automatic switches, relays, starting appliances, and lubrication with heavy rolling and pitching. Here, uniformity was obtained by laying down the rule that in forming an estimate of the worst position which any part of the installation might take up, general requirements are met if safe working is ensured for an inclination of $22\frac{1}{2}^\circ$ in any direction. Considerable discussion also arose in connection with lead coverings for cables, as in some countries trouble had been experienced owing to corrosion and intercrystalline changes at the points of attachment of uncovered cables. On this point British representatives submitted several amendments, and objections were also raised to the proposed tests for the quality and durability of rubber insulation, as good results were obtained by British cable manufacturers by methods differing from those employed on the Continent, notably in Holland. These subjects were further discussed at The Hague in September, 1937 (see continuation). The sub-committee dealing with distribution systems presented a report which also includes single pole d.c. installations and laid down limits and standards of working voltages for both direct and alternating current, installations of the latter type having now reached power outputs (12,000 kW.) at which their adoption in passenger vessels merits serious consideration owing to the possibility of utilizing the advantages associated with the short circuited motors in comparison with d.c. commutator motors. In these rules particular attention is given to the safety of the contacts in a.c. installations and to the correct choice of the voltage for different capacities and purposes.—(*To be continued*). *"Het Schip", Vol. 20, No. 5, 4th March, 1938, p. 42.*

(*Continued*).

Continuing the review of the work done by the International Electrical Commission in the preparation of Rules for Marine Electrical Installations, the writer gives particulars of the report presented to the I.E.C. conference held at The Hague in September, 1937, by Sub-committees VI and IV, which respectively dealt with distribution and cables. The work of the former had been subdivided among the member countries, Holland dealing with the general lay-out, switch gear, main switchboards and distribution boxes, France with the distribution net, and Britain with the distribution appliances appertaining to the motors, while the framing of special rules for the so-called series or Austin system had been allotted to Italy. The rules which have been formulated cover the following points:—Main current distribution and earthing, emergency installations, arrangement and construction of main switchboards and distribution boards for the different systems of distribution, requirements respecting safety devices and fuses, including those fitted to apparatus not mounted on switchboards and for secondary and tertiary distribution boxes; lay-out and protection of cables; rules for fittings and accessories including wall sockets, rules for appliances fitted to motors, such as resistances, switch boxes, controllers and relays, special rules for the series system of distribution and a general tabulation of the current ratings of apparatus and appliances. Details of the limits of heating up in switch fuses and relays, rules regarding the choice of switches, and requirements for small automatic switches remain to be drafted. Sub-committee IV dealing with cables has now prepared precise and complete rules for rubber-insulated cables (excluding cables for propelling installations and thin cables). Values are given for the maximum copper resistances taking account of the type of cable, of the galvanising and of the tolerances on the thickness of the wire. The decision as to the number of layers of rubber insulation is left to the manufacturer, but in the case of single layer insulation, the dangers arising from any eccentricity of the copper core have been met by the provision that the minimum thickness of the insulation must not be less than 15 mm. + 10% below the nominal thickness. As regards the quality of rubber insulation the Dutch representatives pressed for tests on the basis of tensile strength and ageing, but as doubts regarding the value of such tests remain and investigations on these points are not yet complete general rules for international application have in the meantime been dispensed with. Uncovered cables and armoured cables must be cased in lead or lead alloy, the composition of lead alloys being laid down in the rules, and armoured cables must further be fitted with a protective layer of paper containing a small percentage of oil or asphalt. In order to prevent defects due to excessive heating the Committee has drawn up a table of current loadings for the different cables which will ensure that the loading will not increase the temperature of the cable beyond 50° C. (122° F.), taking 40° C. (104° F.) as the normal temperature of the space in which the cable is situated.—*"Het Schip", Vol. 20, No. 6, 18th March, 1938; p. 52.*

Medium and High Speed Diesel Engines for Marine Service.

It is pointed out that Mr. Ricardo's proposals. put forward in 1933, for utilizing a large number of small high-speed Diesel engines for marine propulsion have not been put into effect, as in actual fact it has been proved impracticable to couple together a large number of engines, if a reasonable degree of simplicity is to be retained. Since then, however, high-speed engines of larger output have been developed and there are now new types specially adapted for traction and marine purposes. It is stated that to-day designers of such engines need not have any fears with regard to perfect combustion at any load or speed at which the engine can be run mechanically, and in support of this statement particulars are given of the Ricardo Mark III Comet combustion chamber which is successfully employed in Paxman engines over a range of bore extending from 3½in. to 20in. Making use only of commercial materials it is possible to run at speeds up to 1,500 r.p.m. with an engine of 7in. bore and 7¾in. stroke, or 1,100 r.p.m. if the stroke/bore ratio is increased to give 10¼in. stroke, without imposing stresses in any way greater than usual. A detailed description is given of two of the main series of Paxman engines, viz.: 7in. bore built with 7¾in. stroke as a vee engine and with 10¼in. stroke as a straight vertical engine, and 9½in. bore with 12in. and 17in. respectively and a comparison shows that the vee engine saves enormously in weight and in every dimension. Further, owing to the smaller cylinders it is permissible to run both at higher speeds and higher ratings, the 7in. cylinder being capable of being operated at a b.m.e.p. of 150lb. per sq. in. at speeds up to 1,750 r.p.m., which corresponds to a piston speed of 2,260ft. per min. when supercharged to a pressure of 7lb. per sq. in., while at 115lb. per sq. in. b.m.e.p. with supercharging and 1,150 r.p.m. a 12-cylinder engine will continuously develop 600 b.h.p., and a 16-cylinder engine consisting of two banks of 8 cylinders 800 b.h.p. They lend themselves favourably to coupling up to electric generators and particulars are given of their application to a.c. propulsion installations. Here spring mountings entirely prevent the transmission of any vibration from the machinery to the hull and the small overall dimensions permit the enclosure of the engines in sound-proof casings. Their small size also makes them specially suitable for vessels in which the headroom in the machinery space is restricted, such as day passenger steamers and vehicular ferries, while in coasters and tankers they can be mounted on a flat right aft above the propelling motors. Remote control and starting is accomplished either electrically or by compressed air in a simple manner. It is also stated that high-power light-weight engines have another field in the direct propulsion of the light-weight high-speed craft that have hitherto been restricted to petrol engines, and in conclusion the author gives particulars of several alternative schemes for a 10,000 s.h.p. Diesel-electric installation using high and medium speed engines of the type described in the paper.—*E. P. Paxman, M.A. Trans. of The Institution of Engineers & Shipbuilders in Scotland, March, 1938.*

Alloy Steels.

Various steels and their properties are enumerated, particularly substitute steels intended to economize foreign exchange. The nicrotherm (NCT) group are easily workable, strong at high temperatures, and electrically-weldable by the resistance method. The range of composition of the various members of the group is stated to be 1·8 to 2·2% ni., 2·1 to 4·5% cr., 0·15 to 0·8% mo., and they show tensile strengths up to 48 tons per sq. in., with good elongation. The ferrotherm series, containing chromium and silicon, are also heat-resisting, though less strong, at normal temperature, than the NCT steels. They find application for various parts of marine Diesel engines. As a substitute for heat- and abrasion-resisting steels with a high tungsten content, manganese-vanadium-silicon and molybdenum-copper steels are available. An air-hardening steel for castings has the composition 1·35% mn., 0·6% cr., 1·15% ni., 0·35% mo. A steel for ball-bearings contains 0·95 to 1·1% c., 1·2 to 1·5% cr., 0·3 mo. Manganese-vanadium and chrome-vanadium steels possess a very fine structure and are not susceptible to damage by overheating; they are suitable for marine crankshafts, since the properties are uniform throughout the mass. A tensile strength exceeding 50 tons per sq. in., with an elastic limit of 35 tons per sq. in., can be obtained, and vanadium confers high resistance to shock and fatigue. The steels are weldable with a suitable alloy electrode, and adaptable to the nitriding process. Mention is also made of alloy castings such as Monel cast iron, which can be used for shafts, and is comparable with nickel steel in properties. Molybdenum is also a valuable constituent in castings such as pistons. The centrifugal process of casting greatly improves the purity and quality, and is suitable for cylinders, bearings, pistons and piston-rings. In repair work, the use of alloy electrodes to build up worn parts is important; for high resistance to abrasion, material containing tungsten carbide is employed.—*A. Karsten, "Schiffbau", 15th March, 1938, pp. 98-100.*

Steam Turbine Performance at Partial Loads.

The efficiency of a large turbine working at reduced load falls off less rapidly than would be anticipated for a small machine designed for the same steam conditions. If the adiabatic heat-drop is small, the fall in efficiency is comparatively large. The author investigates the question with the object of deducing quantitative laws simple enough for practical application. Throttle governing, with or without nozzle cut-out, is the most usual method. Losses under throttle governing, viz.: external losses in bearings, alternator, etc., reduction in heat available, variation of exhaust pressure, change in internal efficiency (usually small) are considered in detail. The author goes on to discuss governing by nozzle cut-out and by batching, and ends with a section on single-stage turbines. His methods are claimed to be applicable to many types, including condensing turbines with constant or varying vacuum, back pressure machines, mixed turbines running on steam at high or low pressure, with constant or varying vacuum in either case, but not directly to pass-out turbines. For throttle-governing, no involved calculations are necessary and with *any method of governing, the performance is analogous with that under throttle governing.* This fact is particularly useful to the designer, since the improvement effected by nozzle control can usually be estimated with sufficient accuracy.—*H. G. Yates, "The Engineer", 28th Jan., 1938, pp. 98-99, 4th Feb., pp. 128-130, 11th Feb., pp. 155-157.*

250-Ton Floating Crane for Brest Dockyard.

Modern warships are more than ever dependent on dockyard facilities for handling heavy weights, this being accentuated by the size and grouping of modern naval guns. In 1914 at Wilhelmshaven and in 1920 at Portsmouth, *Demag* installed 250-ton floating cranes with steam-electric mechanism; the new crane has Diesel-electric drive throughout, even to the propellers. It is 197ft. × 102ft. measured over the pitch-pine fenders which run all round, with normal freeboard of 9ft., rectangular in plan, with rounded corners. The flat bottom of ½in. ingot iron is swept up at the after end to accommodate twin propellers. The sides, the ⅜in. deck, the angles and channels of the framing are of open-hearth steel 32 tons/in.^{2} The hull is riveted throughout with four longitudinal and seven transverse watertight bulkheads, the deck being specially strengthened and the bottom cement coated. The crane proper rests on a central pyramid, supported on two inner longitudinal bulkheads, the four corner towers being continued down to the bottom of the pontoon. For safety, the two outer longitudinal bulkheads are 10ft. inboard; the wings thus formed contain no machinery and the unloaded crane can float with three main compartments flooded. Machinery is placed in line with the tower, motors and gearing aft, and living quarters forward. Special precautions to combat side-sway during lifting, or from wind-pressure, are described in full. To prevent entry of sea-water, all rivet holes were cleaned and coated with red lead. Special attention is paid to accessibility. Under overload conditions and with a wind-pressure of 51lb./ft.^{2}, maximum stress in the frame is 8¼ tons/in.^{2}, and in the jib 8·9 tons/in.^{2}, the steels used in construction having strengths of 27 and 32 tons/in.^{2} respectively. A load of 250 tons can be raised 43-60ft. from either end or side of the pontoon, 110ft. from the pyramid, up to 170ft. above water level. The main bearing and actual "bell" of the crane are described in detail. A four-cylinder Diesel engine (180 h.p. at 810 r.p.m.) is coupled to an 80 kW., 200 v., d.c. generator for use either directly or with Ward-Leonard control. A 136-h.p. three-phase motor and auxiliary Diesel 30 h.p. d.c. motor-generator, air compressor (440lb./in.^{2}), and a 40-h.p. three-phase motor, are also fitted. Auxiliary a.c. motors enable shore current to be used in emergency. Batteries are used for telephone and stand-by lighting supply. The equipment includes two centrifugal pumps, bilge pump, fire pump, and lubricating-oil pump, but gravity feed is used for fresh water. Propeller steering is employed. Apparatus for rope storage, hoisting, slewing and winding is described in detail with full diagrams.

The forged-steel worm works with a phosphor-bronze wheel, with special anti-overload devices. Electromagnetic braking can be applied in any position while the crane is stationary, and must be released by push-button before current can enter the slewing motor. The control-gear operates from the driver's cab to start, stop or reverse, to couple main winches and luffing gear or to operate the crab travel, the positions being shown by indicators. Overload cut-outs for the motors are included, but the load cannot itself take charge. Any motor can be stopped instantly by push-button. The main control drum has 11 normal and 4 rapid speeds, the latter available only after releasing a mechanical lock. In general, all toothed-wheels, travelling-wheels and brake-disks are of high tensile crucible steel; axles, shafts and pinions are of forged open-hearth steel. Brake bands are wood lined. Drums, sheaves, guide pulleys and bearings are of close-grained cast iron, other parts of cast or wrought iron. Large jib-journals and other highly stressed parts are of forged high-tensile steel. After delivery the crane was tested at overload and found completely satisfactory.—*"Engineering", 21st Jan., 1938, pp. 75-76; 4th Feb., 1938 pp. 128-130.*

Trends in Steam Generator Design.

In the past, the main trends, induced by improvements in prime movers, demands for increased fuel economy, reliability and availability, and reduced cost of maintenance and operation, were (1) Adoption of superheaters and economisers, (2) Substitution of water- or steam-cooled walls for refractory walls, (3) Use of pulverised fuel and consequent removal of firing equipment from within the furnace, (4) Increase in size, (5) Increase in pressure and temperature of the steam, and (6) Steam washing.

Limits to economical generator efficiency have long ago been reached, but capacity limits for individual plants are not yet in sight. Limits to steam pressures have still to be attained, but this is a factor in the design of prime movers rather than of steam generators. Temperature limits are determined by the physical properties of materials and will rise as improvements occur. Modern engineers aim at delivering clean steam, uninterruptedly, within narrow predetermined temperature limits. The author discusses these points, especially in reference to present-day firing with pulverised fuel. In all cases actual design represents a compromise between high furnace exit gas temperatures (so that the constantly rising steam temperatures demanded may be attained with reasonably flat, basic load, characteristics) and low furnace inlet gas temperatures (to minimise slagging of tubes at the boiler entrance). The specification of some users, that the latter shall not exceed the ash melting-point, greatly increases the difficulty of efficient design. He suggests that in practice the ash particles will actually be cooler than the surrounding gases, provided the coal is sufficiently fine ground. This will account for several observed facts, *e.g.,* the increased slagging with coarse powder and with coking coals. He would design boilers for exit temperatures 150-200° F. *above* the lowest fusion-point anticipated, *ensuring that the largest particles are frozen,* with slag screens and superheater tubes arranged vertically to promote self-cleaning. Special provision to shield the boiler entrance and superheater from direct flame radiation, will lead to higher temperatures of the exit gases. In general, superheat decreases after cleaning out the furnace, and again increases as the tubes become dirty externally. Recent design is retreating from the small hard-driven furnace formerly in favour, the ash making it difficult to use oil-firing technique. Another important problem is the high-pressure joint, but this has now been solved up to 1,525lb./in.^{2}; notwithstanding this, the tendency is to use continuous welded loop economisers. Superheater design is discussed in general, the difficulties increasing markedly with rising temperatures. The author would use no stressed supports exposed to hot gases but would allow the elements to hang vertically from external headers, thus increasing cleanliness and availability. The single- and double-drum methods of steam washing are discussed in detail, and the question of desuperheating *v.* by-passing for control of steam temperatures is investigated critically.—*M. Frisch. Lecture to the American Society of Mechanical Engineers, 18th Nov., 1937; reproduced in "The Engineer", 11th March, 1937, pp. 287-288.*

Welding in Shipbuilding.

The author traces the history of welding from an all-welded cross-channel barge constructed on the Clyde in 1918, the first large-scale use of arc-welding being in the 12,000-ton German motor liners "Caribia" and "Cordillera" built in 1932. In these ships welding was restricted to members carrying minor stresses, but even so it led to a saving of 4 per cent. of the weight. Welding is now used increasingly, in conjunction with riveting, especially for insulated ships and tankers in which special requirements as to gas or oil tightness must be met. The bulkheads are usually pre-fabricated in as large sections as can be lifted, and, together with machinery casings and deck houses, attached in the berth. In the 27,000-ton motor liner "Dominion Monarch" now building, welding is used for bulkheads, tank top and decks. In tanker construction the transverse and longitudinal bulkheads are usually welded and attached to the riveted skin; but all-welded construction is now established for smaller craft 150-300ft. long, *e.g.,* ferry-boats, cargo boats and minesweeper sloops, and welding together with riveting is used extensively in warships at present building, *e.g.,* the aircraft carrier "Ark Royal" is so constructed over a length of 120ft. from the bow. In three 18,000-ton deadweight U.S.A. tankers now building, the whole tank space

(350ft.) is welded, including the shell plating, so that the large all-welded ship is within sight. An automatic welding machine is said to increase speed and eliminate difficulties from warping and shrinkage. The saving in weight for a given carrying capacity is about 15 per cent., and allowing for electrodes and overhead charges the net saving in cost is about 10 per cent. The author considers that to obtain the fullest benefit, yard reorganisation and capital outlay are necessary, and that all-welded design may so greatly affect shipping economics that its more general adoption may reasonably be anticipated.—*"Times Trade and Engineering", Feb., 1938, p. 33.*

Coal versus Oil as a Marine Fuel—Economic Considerations.

Three interesting instances of recent orders for pairs of ships for the same company, one oil-burning and the other coal-burning, are discussed critically. In general, voyage conditions for these vessels will not vary greatly, and the range of engine power—2,000-3,500 h.p.—would embrace two-thirds of British mercantile tonnage. In motor ships to-day the tendency is for auxiliaries to be steam-driven by use of an exhaust-gas boiler, with consequent fuel saving. Steam winches are installed for port-working, so that first cost of equipment is reduced but running costs of fuel-oil for steam raising are high. The disability of coal bunkers can now be taken account of satisfactorily. Maintenance and upkeep costs are quite accurately known for both types of machinery, and wages costs are about equal. The author comes to the conclusion that the choice of pairs of ships of different types is to allow use of either fuel at will, and that the old rivalry is losing its significance. The present annual consumption of fourteen million tons of bunker coal is less than half that before the war. Improvements in design leading to fuel economy react in favour of coal, but further scope for such improvements is limited. Thus the oil *versus* coal controversy becomes economic rather than technical, and the present price of coal is at the limit at which it can compete with oil in marine work.—*"Times Trade and Engineering", March, 1938, p. 34.*

Construction Costs of Motor Ships.

Recently the American government invited tenders for eight cargo ships of length 453ft., deadweight capacity 9,300 tons, speeds 15½ knots, four to be fitted with Diesel engines and four with steam plant. No cargo ship has been constructed in U.S.A. for about fifteen years, but even so the prices quoted were astonishingly high and varied; for motor-ships £39-£69 per ton and for steamers not very different. Even the cheapest motor ship would thus require to earn £60,000 *per annum* to cover fixed charges alone. During 1937 many vessels up to 1,000 tons deadweight for British coasting trade have been built in Holland with German Diesel engines; these are of good type and probably available at lower prices than corresponding British engines. Diesel-engined ships recently built in this country include a large coaster for the Australia-Tasmania trade, of length 235ft., beam 45ft., draft 12ft., deadweight capacity 1,500 tons, equipped with two British 640-b.h.p. two-stroke trunk-piston type Diesels running at 260 r.p.m. A Trinity House inspection boat "Patricia", with a high standard of accommodation for committee members, is another instance. Many other Diesel-electric ships will be placed in service in 1938, including passenger liners up to 25,000 tons gross. Orders for 1½ million gross ton tankers are still being placed for delivery in two years, *e.g.* an 18,500-ton twin-screw vessel with 7,000 h.p. four-stroke supercharged machinery for a French firm, and a 15,000-ton ship for foreign owners to be built on the Clyde. Another tanker with four-stroke supercharged engines has been placed in Holland, a Swedish firm has ordered a 15,000-ton ship in Denmark, and Norwegian owners have ordered three more electrically-welded tankers of 13,000-15,000 tons in Sweden.—*"Times Trade and Engineering", March, 1938, p. 34.*

An Eight-Cylinder Aero Oil Pump.

Particulars are given of the construction and of tests of a new pump invented by Air Commodore J. A. Chamier especially to meet the needs of aircraft. The design of this is based on the well-known form of right-angled drive in which two cylinder blocks mounted in bearings with their axes at right angles are so arranged that they can be rotated by a common worm. Axially along each block four "cylinders" are bored into which right-angled plungers fit in such a manner that as a result of the rotation of the blocks they are constrained to reciprocate relatively to the cylinders. Use is then made of the rotation to control the entry and discharge of the fluid, each block having an extension which has four ports communicating with the respective cylinders. These ports rotate within the fixed parts of the body of the pump in which are formed annular passages communicating with the suction and delivery pipes, to which the ports open alternatively by reason of the rotation. To suit aircraft requirements, the main body of the pump is made of light alloy; the plungers are of steel, and the cylinder blocks which are formed solid with the worm wheels of phosphor bronze. The worm is designed to be driven directly by the aero engine to which the pump is connected, and the reduction is such that the blocks rotate at 325 r.p.m. The pump tested has a weight of 17 lb. for an output of 122 gallons per hour on a calibration test at 2,250 r.p.m., 1,000 lb. per sq. in. delivery pressure, 6in. suction lift, and 1·5 h.p. power consumption; the fluid is oil to Air Ministry specification D.T.D. 44 B. at 55° F. On an endurance test, the pump completed 110 hours running consisting of 11 periods of ten hours each at 2,250 r.p.m., and on a high speed test the pump ran for 30 minutes at 3,250 r.p.m. circulating fluid. It is further stated to be the intention of the inventor to endeavour to develop an aero engine operating on the same principle. — *"The Engineer", 18th March, 1938; p. 313.*

Ships' Speed Meters.

The author after briefly describing the methods and instruments which are in general use for the determination of speed at sea and discussing the sources of the inaccuracies to which they are subject, gives particulars of the speed meter which has been developed at the Hamburg Tank since 1930, when it became necessary to measure the speed of the "Bremen" on her trial trip—the previous method of measurement by means of a resistance log having been found unsuitable at speeds over 22 knots. The calibration here employed is based on ratio between the pressure indications of a set of static and dynamic pitot tubes, the dynamic pressure tube being placed in the stem of the ship where it is not subject to any stream disturbance, while two static tubes are disposed—one on each side—at points of the ship's length where an investigation of the pressure distribution round the hull shows that there are no pressure fluctuations with changing speeds. Mercury in a concentrically arranged U-tube is used as the measuring medium. The impact or dynamic pressure at the ship's stem is conveyed by pipe line to the top of the outer concentric tube and this pressure causes the mercury to rise up the inner tube into a sealed hydraulic chamber above. The static pressure is similarly conveyed from the ship's sides to the top of this chamber and tends to retard the rise of the mercury, on the upper surface of which a float then rises and falls with the difference between the two pressures as determined by the speed of the ship. In the centre of the float is a vertical rack which engages with a pinion and transforms the vertical movement of the surface of the mercury into a rotary movement of the pinion. This is transmitted to the outside by a pair of two co-axially mounted permanent magnets, viz., one mounted inside on the pinion shaft, the other mounted outside on the shaft of a cam in the form of a geometrical spiral proportioned from tank and laboratory tests in such a manner that it transmits the correct movement and follows the pressure characteristics of the ship's speed. From the cam a transmission lever and gear wheels further transmit the movement to the pointer of a dial which shows the speed in knots. In addition, an integrating device can be incorporated in the apparatus for the recording of distances run, and electrical methods are employed to transmit records of speeds and distance to the bridge and other points in the ship. Arrangements can also be made to record the propeller speed at the same time as the ship's speed in the form of graphs from which the slip of the propeller at any time can be determined by the aid of a nomogram. The author illustrates the uses of the accurate records obtainable as an aid to economic ship operation and states that the speed meter is particularly useful to navigators in indicating the diminution of speed in shallow waters. Experience also shows that bad weather conditions with the ship pitching do not affect the measurements, even if the holes in the stem rise clear out of the water.—*H. Hoppe, Trans. of Institution of Engineers and Shipbuilders in Scotland, 12th April, 1938, Paper No. 988.*

Naval Constructors.

Discussing, editorially, the openings available to young technicians in the Royal Corps of Naval Constructors, special attention is drawn to the appointments offered in this branch of the Naval Service to candidates from the universities, two graduates being now taken in any one year in normal circumstances. It is pointed out that in their case entrance to the Corps—health and so on being satisfactory—depends solely upon the candidate's success in the Final Honours Examination, and a practical training in naval architecture is not called for, eighteen months being spent at Devonport Dockyard for this purpose on entry, followed by six months at sea, and a two years' course at the Royal Naval College, Greenwich. The young officers rank as constructor lieutenants and are paid at the rate of 13s. 6d. a day with certain allowances, and whilst they are ashore they are quartered in the Royal Naval Barracks.

The writer considers that this course compares favourably with the course followed by those who leave the university to serve a three years' apprenticeship in engineering works or shipyards and stresses the advantage of the Civil Service conditions offered by the Corps, viz.: permanent occupation and a pension of one-eightieth of the salary on retirement for every year of pensionable service, which includes the period of training, subject to a maximum of forty eightieths, in addition to which civil servants receive a lump sum gratuity of three-eightieths of their salary at the time of retirement for every year of pensionable service subject to a maximum of one and a half times the salary on retirement.—*"The Engineer", 11th March, 1938, p. 280.*

Open Water Tests with Modern Propeller Forms.

The author presents, in a form suitable for analysis and design, the results of three series of tests on four-bladed model screws, the main characteristics of which are as follows:—

Series	A.4.40	B.4.40
Disc area ratio	0·4	0·4
Blade outline	Narrow tip	Wide tip
Blade sections	Aerofoil	Aerofoil at root, segmental at tip.

The third series, B.4.55, is similar to B.4.40 except for an increase in disc area ratio to 0·55. Factors common to all the models are: pitch reduction at root 20 per cent.; range of pitch ratio covered 0·6 to 1·4. The Reynolds number of the tests was for the A series $1{\cdot}4 \times 10^5$, and for the B series 2×10^5. The B series show a very slight drop in efficiency as compared with the A series.—*L. Troost, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Measurement of Wake.

The author discusses the analysis of wake into its various components—streamline, frictional and wave wake—compares different methods of measurement for the model, and cites evidence on the subject of scale effect in going from the model to the ship. He derives an expression for the relation between the streamline wake and the corresponding thrust deduction, to which must be added the frictional thrust deduction. The wake behind a ship model can be found either indirectly from the model screw results, or directly by means of blade wheels or pitot tubes. In the former case the results may differ according to whether the thrust or torque values are utilized, and in the latter there are different methods of averaging over the disc, which do not all yield identical results. As regards the relation between the directly and indirectly determined values, the torque wakes are stated to be in fair agreement with the volume mean of blade-wheel or pitot tube readings, in general. The ship frictional wake is appreciably less than that of the model, but there is little direct evidence on other scale effects, a knowledge of which would allow a satisfactory correlation of model and ship results.—*F. Horn, Trans. of N.E.C. Inst. of E and S., 31st March, 1938.*

Qualities of a Propeller Alone and Behind a Ship.

The author discusses the effects of various departures from open-water conditions which apply behind a ship. Circumferential wake variation tends to be detrimental to efficiency, and increases the liability to cavitation. Radial wake variation can be met by pitch variation. Fore and aft variation may also have some effect, but turbulence is apparently not harmful. Wind-tunnel tests show large hysteresis effects on lift and drag of aerofoils in the region of the stall, and this region should therefore be avoided. Types of sections which develop high local values of suction on the back do not in practice realize behind the ship the high efficiencies which the open or behind model results may indicate.—*G. S. Baker, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Aerofoil Sections in Screw Propellers.

Results of tank tests on lift, drag and pressure distribution are given for five sections: A, segmental; B, "Clark Y" aerofoil; C, modified segmental with rounded nose; D, sharp-nosed "Clark Y"; E, circular back "Clark Y" nose. The Reynolds number of the tests was $3{\cdot}5 \times 10^5$, and all the sections had a thickness ratio 0·12. The sharp-nosed sections show high drag at low incidence, which is elucidated by means of the pressure plotting, and confirmed by certain model screw test results. Both the original and modified circular-back sections show a reduced lift-curve gradient at the higher angles of incidence. The maximum back-suction occurs nearer the nose and is greater in amount for the aerofoil sections than for the others. It is concluded that a well-rounded nose, and lifting the nose relative to the face gives a good result, but the maximum ordinate should not be too far forward, to avoid high suction, if cavitation is likely.—*J. F. Allan, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Model Experiments on the Optimum Diameter of Propeller for a Single-screw Ship.

It is stated that propeller diameters derived from systematic open-water tests are not the optimum for single-screw ships, as the energy of the frictional wake is not taken into account. Accordingly results are presented of tests of seventeen propellers of varying pitch ratio and disc area ratio, behind two models of a vessel of 0·683 block coefficient, one having a smooth surface, and the other roughened to simulate the effect of fouling. It is concluded that the optimum diameter for the smooth model is about 5 per cent. greater than that deduced from open-water tests, whilst for the roughened model the optimum is about 10 per cent. greater still.—*M. Yamagata, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Propellers for Tugs and Trawlers.

The author applies Schaffran's systematic model results for elliptical-bladed segmental-section propellers to ascertain the effect of designing the propeller to absorb the available power at zero speed or at a definite forward speed. He also considers the effect of various types of machinery, insofar as this is represented by the revolutions-torque correlation, the two extreme cases considered being constant torque at varying revolutions, and constant brake horse-power. He states that the calculated static thrusts have been verified by dock trials.—*F. Benson, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Effect of Shaft Brackets on Propeller Performance.

The author discusses the influence of shaft brackets on wake and hull efficiency in the light of model tests. The fitting of brackets before the screw increases the wake slightly and also usually increases the hull efficiency by 2 or 3 per cent. The arms should be inclined in the direction of flow, which is not normally exactly in the diagonal plane. Open-water tests with arms before and abaft the propeller do not reveal any appreciable advantage in the latter case as compared with the normal position. Fitting brackets abaft the screw has the disadvantage of increasing weight of brackets and of shafting. The effect of the flow disturbance caused by the brackets is to tend to increase the liability to cavitation, particularly if the arms are not suitably inclined. Some comparative tests of brackets and solid bossings revealed only slight differences in the efficiency, with the two alternative arrangements.—*Gawn, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Torsion and Torsional Oscillation of Blades.

The author gives methods of calculating the torsional rigidity of blades, and the natural frequencies of vibration, in terms of the rigidity and mass, assuming a knowledge of the amount of the virtual fluid mass. Two methods of obtaining the rigidity, the thickness-parameter method, and the Galerkin method, are given, and detailed results worked out for certain sections. For a thin segment of a circle and similar sections, the rigidity constant is approximately $\frac{16}{105}$ (breadth) × (thickness)^3. An approximate method of calculating the natural frequencies of the lower modes is given and the results compared with the exact solution for a uniform blade. In an appendix there is a note on airscrew flutter.—*Duncan, Trans. of N.E.C. Inst. of E. and S., 31st March, 1938.*

Model Tests on Immersion of Propellers.

The author presents results of tests of four propellers of different pitch, diameter and revolutions behind a single-screw model of 0·728 block coefficient, at three different drafts. At the deepest draft, all the screws are fully immersed, at the intermediate draft the tips of the largest propeller are breaking the surface, whilst at the light draft the largest screw has about two-thirds of its radius out of the water, and the smallest about one-half. The largest, slowest-running propeller is the most efficient under all conditions, and suffers least from partial emersion. The smaller propellers show some gain in efficiency with decreasing draft, so long as their tips are covered, but a large loss at the lightest draft. Wake contours are plotted for the various drafts. The author calculates the effect of scale (change of Reynolds number) on the drag and hence torque of the ship screw as compared with the model, on the assumption that the resistance is independent of slip, and can thus be deduced, for the model, from the torque at zero thrust. He finds that the ship screw efficiency will be increased to 72·8 per cent. as compared with 67·6 per cent. for the model.—*G. Kempf, Trans. of N.E.C. Inst. of E. and S., 1st April, 1938.*

Propeller Performance in Rough Water.

The author discusses the effect of type of engine, as influencing the revolutions-torque correlation, on the maintenance of speed at sea. Reciprocating engines give roughly constant torque, but turbines and electric motors may allow the power to be maintained in spite of reduced revolutions. This, however, tends towards increased loss in propeller efficiency. Under constant power conditions, the large-diameter, small-pitch screw shows to advantage in bad weather, judging by the results of open-water model tests, taken in conjunction with an assumed increase in thrust horse-power required. In general, however, the design which is best for smooth water is also best under rough weather conditions.—*J. L. Kent, Trans. of N.E.C. Inst. of E. and S., 1st April, 1938.*

Sea-Kindliness and Ship Design.

The authors suggest that modern progress in ship design has been principally directed to improved smooth-water performance and not sufficiently to improved behaviour in adverse weather conditions, and they present a discussion of those aspects of sea-kindliness that appear to depend on ship design rather than on the skill of the navigator. In reference to rolling they compare the behaviour of broad and large beamed vessels and they stress the remarkably sea-kindly qualities of timber carriers trading with low metacentric heights. With regard to pitching, they consider that from the design standpoint little is known of the effect of the out-of-water form. They express a preference for a well-designed clipper stem but contend that flare forward appears to avail but little in heavy seas. Regarding stern design they consider that cruiser sterns do not poop any more than cylindrical sterns, but that the really fine-lined cruiser stern is not likely to offer any advantage over a very much fuller and flared out cruiser stern correctly designed in avoiding flat-bottomed sections. The modern heavily raked stem impairs the manœuvring and course-keeping qualities and adversely affects ballast speeds which call for long fine entrances, a feature which is entirely destroyed by excessive rake. Top gallant forecastles, however essential they may be from the dryness standpoint, are probably a definite disadvantage in heavy beam and bow weather, the forecastle or its vicinity being undoubtedly the chief cause of a vessel's inability to turn into the wind and thus falling off her course, so that the adoption of turtle forecastle in large merchant ships appears to be preferable. An analysis of available data for mechanically propelled vessels suggests that a suitable rudder area is given by the formula $A = LD\left(1 - \frac{V}{\sqrt[2]{L}}\right)$, where L D and V are respectively the length, load draught, and speed in knots, and to assist in ballast course-keeping the authors consider the idea of fitting some form of trysail, as in drifters, to be worthy of consideration. Regarding the problem of adequate engine power in heavy weather, the authors state that to ensure against a heavy loss of speed a vessel should be capable of averaging a steam indicated horse power of $16 \times \sqrt{\text{displacement}}$ in tons, the maximum trial power being given by a 30 per cent. addition to this value. In conclusion, the authors describe alternative methods of heaving-to and discuss the possible use of model experiments in assisting the better understanding of sea-kindliness, as well as better interpolation of the freeboard between various types of deck erections.—*Macdonald and Telfer, Trans. N.E.C. Inst. of Engineers and Shipbuilders, 18th March, 1938.*

The Single-Screw Steamship "Anglo Indian".

The single-screw steamship "Anglo Indian", which has been built by Messrs. Short Bros., Ltd. of Sunderland for the Nitrate Producers Steamship Co., Ltd., represents the first "Arcform" vessel to be fitted with the reheater type of engine developed by the North Eastern Marine Engineering Co., Ltd. The vessel, which is of the shelter-deck type, is designed with a raked stem of rounded plate construction in the upper part and a cruiser stern. A fin is fitted to the stern post to promote efficient propulsion and the hull is of fine form, the block coefficient being about ·69. The decks are framed on the longitudinal system; elsewhere the structure is built on the transverse system. The principal hull particulars are as follows:—Length B.P.—426ft.; breadth extr.—61ft. 6in.; depth mld. to shelter deck—36ft. 6in.; deadweight—9,850 tons on 25ft. 5¾in. load draught; the gross and net tonnages are:—5,609 and 3,341 respectively, and the holds and tween decks have an aggregate grain capacity of about 565,500 cub. ft. Eight transverse bulkheads extending to the main deck subdivide the ship into nine compartments. The propelling machinery is situated amidships and there are two holds forward and two aft of the machinery space. A deep tank, alternatively for water ballast or cargo, is arranged immediately abaft, and a large cross bunker for coal immediately forward of the machinery spaces, the total capacities for water ballast, bunker coal, and oil fuel being respectively 2,382 tons, 1,343 tons and 926 tons. The cargo handling equipment consists of eight 5-ton and four 3-ton derricks together with twelve 7in. × 10in. steam winches. The steering gear is of the Wilson-Pirrie telemotor controlled type and the navigational equipment includes echo sounding and wireless direction finding apparatus. The propelling machinery of the "Anglo Indian" is of the triple-expansion reheater type similar to that fitted in the "Lowther Castle" and "Lancaster Castle", the present set being the fifth installation built on this system by the North Eastern Marine Engineering Co. The engine cylinders are of 24, 39, and 68in. bore with 48in. stroke for 2,000 i.h.p. normal output, designed to propel the vessel at a speed of 11 knots. The h.p. and m.p. cylinders are fitted with North Eastern poppet admission and exhaust valves, while the l.p. cylinder, which is located centrally, has a balanced slide valve. Steam is generated in two main cylindrical boilers of 16ft. 1in. diameter and 12ft. 4½in. length at 220 lb. per sq. in., leaving the superheaters at a total temperature of 776° F., corresponding with about 380° F. superheat. The boilers are arranged for coal or oil burning under Howden's forced draught and fitted with tubular air preheaters, soot blowers and superheaters of the North Eastern combustion-chamber type with headers arranged externally on the boiler back plates. In addition, an auxiliary boiler of 12ft. 6in. diameter and 11ft. 6in. length is fitted to supply steam for auxiliaries and for circulating the main superheaters when raising steam for the main boilers. As regards the reheater system, no modifications have been indicated by the experience with earlier ships in which fuel consumptions of 1·00 to 1·05 lb. of coal per i.h.p. per hour and ·80 lb. of oil per i.h.p. per hour for propelling purposes, together with steam consumptions of 8·25 lb. per i.h.p. per hour for the main engine and 10·01 lb. per i.h.p. per hour for all purposes have been realised. On a ballast trial a mean speed of 13·5 knots was obtained.—*"The Shipbuilder and Marine Engine Builder", March, 1938, p. 137.*

The Single-Screw Steamship "Itinda".

This vessel, which was completed by Messrs. William Gray & Co. of West Hartlepool last January, has been built for the coasting trade of the British India Steam Navigation Company to the following principal particulars:—Length b.p.—420ft.; breadth mld. 57ft. 3½in.; depth mld. 34ft. 6in.; 6,620 tons gross, 3,964 tons net, and deadweight 8,700 tons on 25ft. load draft. The design is of the two-deck type with poop, bridge, and forecastle, the under water form being based on hull and propeller model tests carried out at the Teddington Tank. A total grain capacity of about 528,300 cub. ft. is provided in the hold and tween deck spaces, together with permanent bunker space for 750 tons and reserve bunker space for 510 tons of coal in the after bridge tween decks, and about 1,500 tons of water ballast can be accommodated in the double bottom and the peak tanks. The storerooms include a separate specie room and insulated cold stores of about 1,200 cub. ft. capacity. The cargo-handling gear comprises fourteen 7in. × 12in. steam winches and ten 7-ton, two 8-ton, two 5-ton, and one 25-ton steel derrick. The steering gear is of the steam-hydraulic and the rudder of the single-plate type. The electric installation includes fourteen floodlights for cargo working and electric radiators and ceiling fans in the European quarters, current being supplied by a 38 kW. 110 volt d.c. generating set running at 650 r.p.m. The boiler plant and stokehold equipment have been specially designed for the extended use of poor quality Indian coal. Steam is generated in three air-jacketed Howden-Johnson boilers at a working pressure of 250 lb. per sq. in. and the total steam temperature at the superheater outlet is about 600° F., corresponding with about 200° F. of superheat. The boilers are of 15ft. diameter by 7ft. long, and have each three furnaces arranged for coal firing with Howden's system of balanced draught, the forced draught being maintained by a fan driven by two

Drysdale Thermall engines, of which one serves as a stand-by, while the induced-draught fan is driven by a forced-lubricated steam engine having its suction arranged at the base of the funnel. The air preheaters are of the turbulent-flow and the superheaters of the combustion-chamber type, and soot blowers are provided for the cleaning of these elements and of the smoke tubes. The main propelling installation consists of a set of triple-expansion engines having cylinders of 22in., 37in., and 65in. diameter with 48in. stroke working in conjunction with a Bauer-Wach exhaust steam turbine and giving a combined output equivalent to 3,500 i.h.p. at 81 r.p.m. designed to drive the loaded vessel in service at a speed of 12 knots. The h.p. cylinder is fitted with Andrews & Cameron quadruple-opening cam-operated balanced slide valves and the m.p. and l.p. cylinders with similar three-ported valves. Vortex steam separators are fitted to each boiler stop valve and also to the exhaust steam connection from the engine to the turbine. The latter unit transmits power to a built up propeller having a cast iron boss and four bronze blades through double-reduction single-helical gearing and a Vulcan hydraulic coupling. An oil-operated servo-motor moves the change-over valve for passing the engine exhaust steam to the turbine, or alternatively by-passes it direct to the condenser when manœuvring or running astern, and a Michell thrust block is incorporated in the gear casing. The main condenser is of the double-flow regenerative type and feed heating is carried out by a direct contact feed heater together with a surface heater. The auxiliaries include a Weir evaporator of 30 tons capacity, an auxiliary feed circuit with feed pump and condenser, and a lubricating oil circuit for the forced lubrication of the turbine and gearing and also for the servo-motor oil relay with duplicate reciprocating oil pumps, cooler, and purifier. On a ballast trial a mean speed of 13·5 knots was obtained on the measured mile in exceptionally stormy conditions.—*"The Shipbuilder and Marine Engine Builder", March, 1938, p. 132.*

Steam Turbine Construction in Europe and America.

In U.S.A. condensing units up to 25,000 kW. per cylinder are used; the limit, which is set by the maximum permissible speed of the blade-tips, will rise with improved blading. In 3-cylinder tandem or cross-compound designs, larger capacities are available; with non-condensing, superimposed turbines, up to 60,000 kW. in a single cylinder, at 3,000 r.p.m. In Europe condensing multi-cylinder machines with similar outputs and speeds have been built. Theoretically a high speed machine is more efficient because of (1) elimination of end effects in blade and nozzle, (2) friction loss which depends on the square of the diameter, and (3) lower leakage losses. A high-speed machine can work with the same overall efficiency as a slower-speed machine with more stages; further, clearances are more easily maintained owing to compactness. At present 3,000 and 3,600 r.p.m. are the limiting speeds set by two-pole alternators at 50 and 60 cycles respectively, but single-reduction gear with 98 per cent. efficiency is common and could be applied to higher speed turbines; gearing is already common in marine engineering and for large capacity turbines, but in U.S.A. the solid coupling is more popular, and is found to be satisfactory for well-balanced shafts running far from the critical speed. In Britain steam at 850° F. and 650 lb./in^2 is common, in U.S.A. at or over 925° F. and 1,250 lb./in.^{2}; materials may soon be available for use at 1,100-1,200° F. (i.e., at a dull red heat) when pressures up to 2,500 lb./in.^{2} might be practicable. The author concludes that drainage cannot counteract more than one-sixth of the efficiency loss attributable to the moisture, and that therefore reheating should be carefully investigated; little is known of the exact working of drainage devices. Theoretically the Parsons turbine is the most efficient; owing to its lower efficiency the Curtis type is used for small units where robustness and cheapness are essential. From its flat characteristics it is becoming popular as a first stage on large turbines, being by-passed at heavy loads; in this way the advantages of throttle and nozzle governing are combined. The Rateau type has a higher heat-drop and consequently fewer stages; a new design combines Rateau diaphragms and nozzles with Parsons blades. No information is available regarding the practical results of the "constant circulation" theory. Shrouding, Prandtl effect, nozzle and blade design are discussed. He speaks favourably of the Ljungström radial flow double rotation turbine at Brighton, a type not used in U.S.A., being too difficult to construct. Throttle control, in general, is suited to a unit working consistently near its most efficient load, and nozzle control to a widely varying load; in regard to overall efficiency there is little to choose between them; in minimising distortion throttle control has the advantage. For high-speed units very rapid action of governors, relays and valves is essential, and superimposed turbines present difficult problems. Casings should be of simple geometrical form; the double-walled construction is described. Welded casings are simpler and lighter than iron or steel castings, and appear to be satisfactory in use; a welded horizontal joint would eliminate the trouble experienced with steam leakage at high pressures. Various methods of jointing and diaphragm formation are described. High pressure glands give trouble, both by steam leakage and by heating-up of the lubricating oil; the author suggests that an improved water seal with minimised power loss should be devised. Material, design, vibration, shielding and cracking of blades are discussed in detail. He compares standard practice on the following points—number and design of extraction heaters, temperature drop, valve arrangements, starting with and without extraction, removal of condensed water and deaeration. The boiler feed-pump is important in high-pressure plants, where it may consume 400-1,200 kW.; its location in reference to the water heater is critically considered. In general, flue-gas reheaters are preferable to steam reheaters. In U.S.A. oil-pipe joints are welded to reduce fire risk, and self-aligning bearings are more common than in Europe. Michell or Kingsbury thrust-blocks are almost universal. In new installations, turning gear, to revolve at 1—5 r.p.m. during warming-up, is common, and high-pressure oil is pumped into the heavily loaded bearings; the author considers the latter action unnecessary. In the generator, hydrogen cooling increases efficiency by 0·5—1 per cent. To combat vibration, more rigid foundations are now demanded. Factors influencing evaporator design are very varied—scaling propensity of the water, delivery of moisture-free steam, cleaning facility and position, so that a standard design seems impossible. "Reheat" depends on stage efficiency, isentropic heat drop, moisture correction, the steam conditions and the standard data used; new "reheat" tables are now being calculated in U.S.A. "Leaving" losses are not accurately known, in U.S.A. 3 per cent. and in Britain 1½ per cent. of the isentropic heat drop is allowed, but this method of expression is not altogether satisfactory. Still higher efficiencies seem possible by better proportioning of nozzles and blades and by use of new construction materials; higher pressures and temperatures of the steam are likely in future.—*A. G. Christie, "The Engineer", pp. 238-239, 266-267, 296-297; 4th, 11th, 18th March, 1938.*

Pressure Distribution in a Convergent-Divergent Steam Nozzle.

Three difficulties face the engineer in nozzle design; exact allowances for friction are not accurately known; the classical Reynolds' theory assumes uniform pressure and velocity over the whole cross section, ignoring curvature of the streamlines; unless the steam is highly superheated condensation may take place. A mass of information is to-day available regarding the *overall* efficiency of convergent nozzles as used in turbines, much of it obtained with high temperature steam. By using a search tube, Yellott (*Engineering, 137, pp. 303, 333; 1934*) has shown that the pressure-drop along the axis is not continuous, but becomes arrested at the point where visible condensation begins. That a rise in pressure necessarily accompanies condensation was shown theoretically by Keenan and practically by Rettaliata (*Trans. A.S.M.E., 58, p. 599; 1936*); while Taylor (*Aero Research Comm. Report No. 1381; 1930*) has investigated pressure distribution mathematically. In the present work a brass nozzle of rectangular cross section, 0·38in. high, 3·08in., 2·30in., 1·393in. wide at the two ends and the throat respectively, and 11in. long, was used, pressure distribution being measured at thirty-three 0·04in. tappings in the base-block by means of mercury gauges. For experimental reasons, low pressures, not exceeding 25 lb./in.^{2}, were used throughout. The authors' conclusions may be summarised as follow:—Callendar's value of 1·30 for the isentropic expansion index is accurate enough for nozzle calculations, and the pressures at specific points are not sensitive to small changes in this. Discrepancies between experimental results and those predicted by classical theory can be attributed to the effect of friction. By empirical calculations the authors show that a 2 per cent. reduction in the initial converging stage and a 20 per cent. reduction from a point 1½in. beyond the throat fits the observed points very well; a slight undulation in the experimental curve was found to be independent of initial steam pressure and temperature within the range investigated. Analysis by Taylor's theory gives good agreement at the throat but not elsewhere and Reynolds' treatment can be regarded as a first approximation only. The authors have accurately plotted the Wilson line, making allowance for the effects of friction, which are appreciable. In the short range considered, it joins the co-ordinates (1·732, 1108) and (1·805, 1104) for entropy and total heat expressed in British units. A sudden pressure rise from the point on the line where condensation begins has invariably been observed; so clear was this phenomenon that it was not necessary to use a glass slide in the nozzle. The time taken to pass from the supersaturated state at the Wilson line to the peak of the rise is calculated, the trace of these peaks on the Mollier diagram being the "wet steam line" running parallel to and a little above the Wilson line. This leads to the conclusion that *in general, provided the steam at entry is in thermal equilibrium, condensation will not take place in the simple convergent nozzle commonly used in turbines, the steam remaining superheated or supersaturated throughout its passage.* Oscillations as high as ±5 mm. observed on the mercury gauges at the points of condensation are attributed to turbulence resulting from the sudden pressure rise. Analysis shows that at the peak the steam is probably not in thermal equilibrium, and that the rise takes place with a decrease in velocity, increase in total heat, and slight increase in entropy. Results reported by Stodola on the effect of increasing exit pressure, are confirmed; discharge is not affected by rising exit pressure until the ratio of exit to inlet pressures exceeds 0·82. Similar results have been reported by Durand for air (*Aerodynamic Theory, Vol. 3, 1935; Springer-Berlin*). The calculated values of the droplet radii vary from 5·7 to $6{\cdot}9 \times 10^{-8}$ cm. at 127° and 107° F., compared with $2{\cdot}29 \times 10^{-8}$ derived from viscosity experiments by Jeans (1925), for the water molecule.—*Binnie and Woods, "Engineering", pp. 250-251, 283-284; March 4th and 11th, 1938.*