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EVAPORATING AND DISTILLING MACHINERY.

From the earliest times the maintenance of an adequate quantity of fresh water on board ship has presented difficulties, and at least as early as 1684 the question of replenishing supplies by treatment of sea water had reached the stage of practical experiment. In that year the Captain of H.M.S. "Mermaid," in a letter signed by Samuel Pepys and endorsed by Charles II, was directed to receive on board and report upon "An engine for producing Fresh Water (at Sea) out of Salt."*

The immediate outcome of this project is not known but the difficulties of the blackading fleet off Cadiz more than a century later show that it had no permanent result. Even after the introduction of steam for propelling purposes development was slow, and down to about 1890 the general fitting was a simple distiller which condensed steam direct from the boilers. With the introduction of water-tube boilers, however (c. 1900), requiring a high standard of purity for the feed water, the question assumed greater importance, which subsequent demands for reduced weights in the reserve and storage tanks, and improved living conditions for the personnel have only increased.

Although the basic principle of the evaporating and distilling plant, namely, the boiling of a low grade water and condensation of the pure vapour thus set free is very simple, its economical application on a large scale introduces several features of interest.

The primary requirements are purity of product and economy in working, to which must be added, in the case of ships' plants, conservation of weight and space.

Priming.—Purity of output implies freedom from priming, and this is a defect to which sea-water evaporators are particularly liable due to the vigorous foaming at the surface of the brine; trouble from this source, due largely to over-concern for the weight and bulk of the plant, was met with at one period in service designs. Experience quickly showed that it was inadmissible to reduce the ratio of brine surface to vapour output beyond a certain limit, and that the provision of an adequate dome height above the brine and an effective baffle below the vapour outlet were essential.

The minimum permissible brine area varies with the conditions in the shell. Priming occurs when the velocity of the liberated steam rises above a certain amount and clearly for a given output this limiting velocity will be soonest reached when the specific

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* *Original in the library of Worcester College, Oxford. The attempt created widespread interest. The benefits to be expected were extolled at length by Edmund Arwaker in "A Poem on the Excellent and Useful Invention of Making Sea-Water Fresh," from which it appears that the preliminary experiments were prolonged and that Boyle was associated with them.*

volume of the vapour is large, *i.e.*, when the pressure in the shell is low. For evaporators designed to work under varying conditions it is necessary, therefore, to provide sufficient area to prevent priming from this cause under the highest vacuum which will be carried.

The height of dome cannot be calculated. Theoretically the amount of entrainment of the liquid should increase :—

(1) as the diameter of the drops decreases.

(2) the difference of density between the vapour and the liquid decreases.

(3) the viscosity of the vapour increases.

These conditions cannot be estimated with any accuracy and the proportions adopted have been arrived at as the result of experience. It will be evident, however, that for a given velocity of vapour and a drop smaller than a certain limit, no extension of the dome height however great will prevent entrainment, so that other methods—baffles—are necessary.

Baffles for separating an entrained liquid from a vapour should be constructed so as to make the mixture pass round a sharp corner at high velocity. The change in direction is more readily made by the vapour than the entrained drops (due to the greater momentum of the latter) and the drops on coming into contact with a wet surface coalesce with the surface film and are not easily picked up again. Care must be taken, however, that the deposited water can drain away in such a way that it does not drop off into high velocity vapour and again become entrained.

Absence of priming is dependent also on a constant rate of evaporation, and this demands the maintenance of a steady and consistent brine density, a fixed level in the shell, a regular flow of the brine past the heating surfaces, and a constant pressure both in the shell and the coils.

To keep the brine density constant, it must be withdrawn continuously at a rate proportional to the incoming feed. To reduce the heat-loss it is customary to use the highest density which can be safely carried without exceeding the saturation limit of salt. Thirty by hydrometer,* *i.e.*, three times the density of sea water, has been fixed as the safe maximum, and the rate of withdrawal must therefore be not less than one-third that of the entering feed. To prevent vapour-locks and deposition of salt, due to self-vapourisation consequent upon the pressure in the pipes and fittings being somewhat lower than that in the shell, the brine is cooled and diluted by sea water taken from the distiller cooling circuit.

The level of the brine in the shell is maintained by an automatic feed regulator which should be set so that the coils are completely covered when seen through the window in the shell.

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* Often referred to as 3/32, because sea-water at 200° F. contains about 1/32, by weight, solid matter.

This level, due to surface foaming, will appear some inches higher than that shown in the gauge glass.

Circulation and consistent density is ensured by placing apron plates round the outside of the coils; the feed enters into the annular space thus formed, passing under the plates and up through the coils to the surface. At the surface, partial evaporation is accompanied by a downflow of denser residue over the top of the plates into the annular space again, where it mixes intimately with the relatively fresher water of the incoming feed and repeats the circuit.

As regards the coil and shell pressures, that in the shell is the more important, not only because any sudden drop may induce priming directly, but also because it influences in two ways the rate at which heat is transmitted to the brine. Air is always present in the feed water and most of it is liberated at the tube surface. As the pressure in the shell falls the volume of this air increases and blankets off an increasing area of the coil surface. Hence fluctuations in the shell pressure cause changes in the effective area of the heating surface. In addition, the coil and shell pressures govern the temperature difference between the coils and the brine, on which, other things being equal, the rate of heat-transmission depends.

In fixing the heating surface required for a given output, it is necessary therefore to allow not only for the effect of scaling, but also for the blanketing effect of the air at its maximum, that is, when working with a high vacuum in the shell. Fortunately the temperature difference is also usually greatest in this condition of working (*see* diagrams) and this effect to some extent offsets the other. The rate of circulation of the brine, its density, and the temperature of the feed water also have their influence, so that considerable experience is required to assess correctly the heating surface required in an evaporator.

Trend of recent design.—The considerations discussed have standardized to a large extent the shape and proportion of the evaporator itself, and recent design has been directed mainly towards improved economy in working by developing the remainder of the plant. In this direction the principal advances have been secured by the use of auxiliary exhaust for the coil steam, pre-heating the feed water, vapour compounding and increased attention to the scaling of the coils.

Auxiliary exhaust, at the expense of increased consumption by the auxiliary engines, gives a net improvement in economy due to the productive use of the steam before its latent heat is pumped overboard in the circulating water of the distiller. This question will be discussed in detail in a future article in these papers.

Pre-heated feed water is usually obtained by passing a portion of the warm circulating water discharged from the distiller through a heater—*or* pre-distiller—in which heat is taken from the vapour on its passage from the evaporator to the distiller proper. In some recent designs this heater is embodied with the distiller itself. Such devices result in an appreciable increase in output for a given quantity of heat supplied to the coils.

Vapour compounding, as applied to Service designs, is a more recent development. In this arrangement the evaporators are worked in sets of two or more to form one unit, the vapour from the first evaporator shell being led to the coils of the second, the vapour of the second (where more than two are fitted) to the coils of the third and so on. The output of the evaporators when used in this way is necessarily less than when working singly and it is usual to provide means for operating them separately when necessary.

Priming in the first effect evaporator, it should be noted, will lead to the coil drain water of the second being contaminated and when this occurs the latter must immediately be switched to the bilge by means of the cock provided.

An evaporator being primarily a heat-transfer apparatus, a knowledge of the temperature at the different parts in various conditions of working is necessary to a general understanding of the plant. With this in view, a diagram (Figs. 1, 2, 3) has been prepared giving typical figures for a recent installation.

Fig. 1 shows the temperatures (red) and pressures (black) at various parts of the plant when working in single effect at full normal output. Fig. 2 the corresponding figures working with a high vacuum in the shell, and Fig. 3 the same plant working in compound effect. The ratio of made water to steam supplied and the rate of output are also given in each case.

The cost of making water in single effect, it will first be noticed, is nearly double that in compound effect. Hence such evaporators should invariably be worked compound unless circumstances absolutely demand the somewhat greater output obtainable by working them separately. Further, the coil pressures are low, the evaporators being designed to give their full output at pressures within that normally carried by the closed exhaust. No opportunity should be neglected, therefore, of making use of this further aid to economy, although in some recent designs it may happen that this will require more foresight than formerly, because the requirements of feed heating and the increasing use of motor driven or self-condensing auxiliaries may not at all times leave an adequate surplus for the evaporators.

As regards pre-heating, the limitations of low-pressure steam should be noticed. Thus, when a high vacuum is carried (Figs. 2 and 3) the great quantity of heat passing from the evaporator to the distiller is so moderate in temperature that heat transfer ceases to be effective when the water reaches about 120° F. This limitation is most serious when working compound, the difference between first effect brine and incoming feed then being nearly 100° F. It is clearly desirable that this

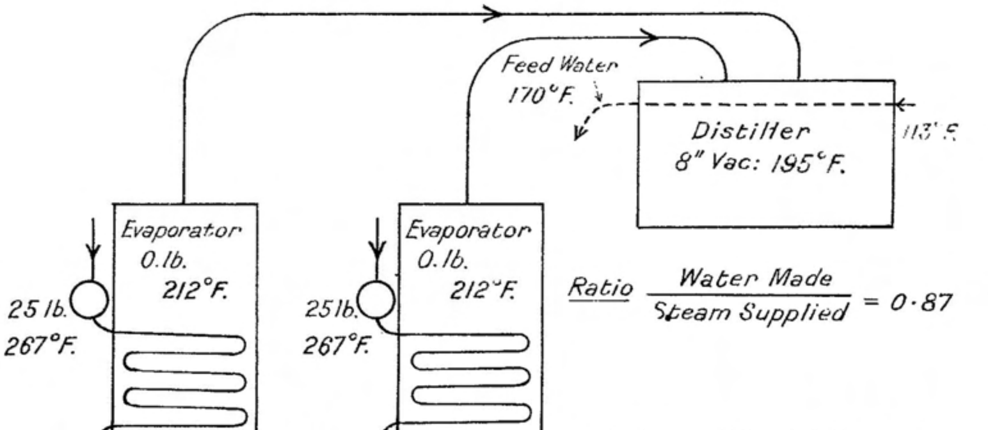

FIG: 1.-SINGLE EFFECT.
FULL NORMAL OUTPUT = 100 TONS/DAY.

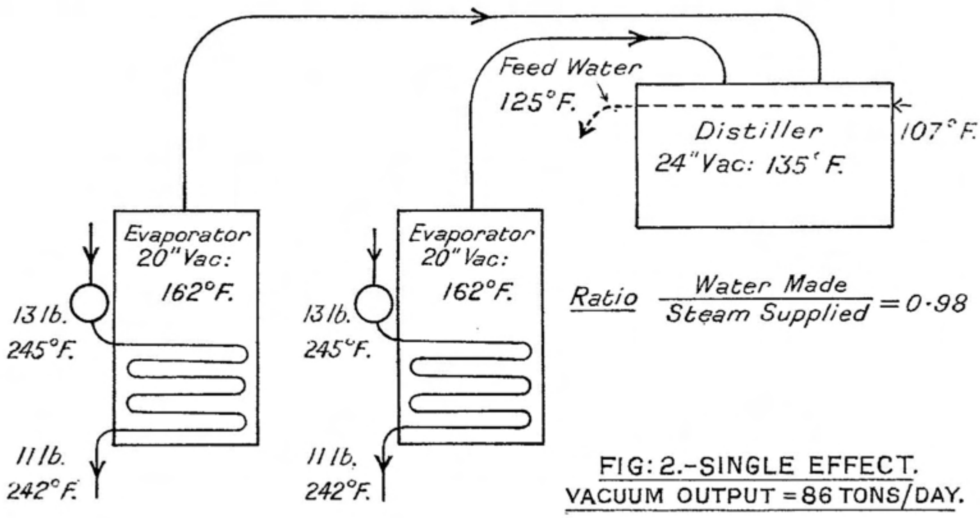

FIG: 2.-SINGLE EFFECT.
VACUUM OUTPUT = 86 TONS/DAY.

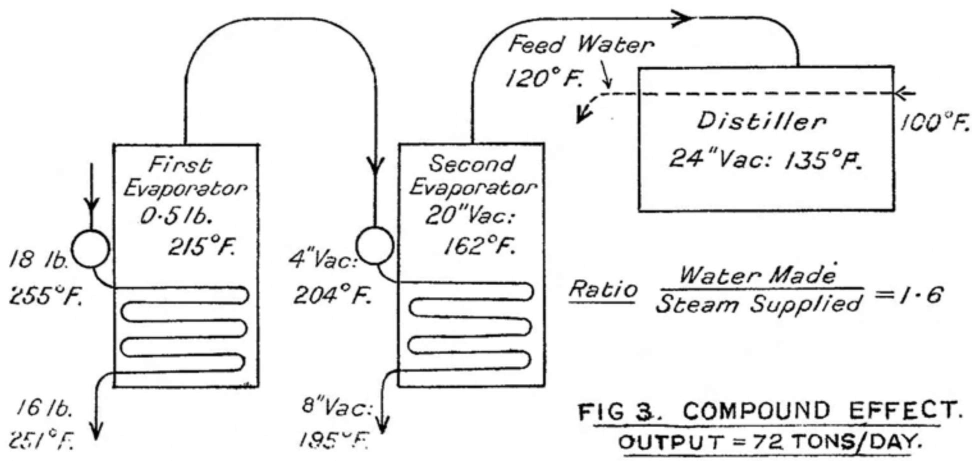

FIG 3. COMPOUND EFFECT.
OUTPUT = 72 TONS/DAY.

difference should be reduced if possible, and the temperature of the coil drains suggest a further source of available heat which has been utilised by some makers. It will also be seen that the difference in pressure between the two shells when working compound makes it possible to blow brine direct from the first to the second and thereby provide feed water for the second at a temperature actually in excess of the boiling point there obtaining. Arrangements are usually made for this to be done, shut-off valves being fitted and provision made for parallel feeding when the evaporators are worked separately.

Series feeding involves, of course, a lower density in the first evaporator than in the second, the figures being of the order of 1·5/32 and 3/32, and this introduces an additional advantage by tending to equalize the rate of formation of scale on the two sets of coils. To explain this it is necessary to consider shortly the process of scale formation—the control of which is vital to economy.

Scale.—The formation of scale on a heating surface is due to the presence in the brine of some substance or substances in such a quantity that the saturation point is passed and solid matter is consequently deposited. The two most important substances present as solutions in sea water are common salt and sulphate of lime ($Ca\ SO_4$). The solubility of common salt is independent of the temperature and no deposition from this cause will occur so long as the density is kept below the saturation limit. Sulphate of lime, however, unlike most substances, has an inverted solubility curve, that is to say, the saturation point (at temperatures above about 140° F.) decreases as the temperature rises.

A given weight of such a substance may thus be insufficient to saturate a certain volume of water when the temperature is, say, 160° F., while giving a heavy deposit at 200° F. In such an instance the hotter film next the heating surface is the place where saturation will first be reached. Deposition of solids will commence consequently in any pits or irregularities in the heating surface, as it is in such places that the solution is hottest. Hence the importance of not bruising the surface of the coils by careless chipping and hammering during scaling, and of restoring the smooth surface as soon as lost.

The scale formed by calcium sulphate is very hard and adherent, and, provided a limiting brine density of 3/32 is not exceeded, is the only scale generally met with in sea water evaporation. When river or nearly fresh water is distilled, however, a considerable soft scale may be formed. This is due to calcium carbonate, which is found in nearly all fresh waters, but only in small quantities in the sea, where the shell fish absorb it to form their shells.

Summarizing, the density at which the hard troublesome scale of $Ca\ SO_4$ commences to deposit decreases as the temperature rises, and in the case of two evaporators working compound, therefore, the low density and high temperature in the first and the converse conditions in the second tend to equalize the rate of scale formation on the two sets of coils.

Clearly, anything which will reduce the amount of scale or facilitate its removal, is worth consideration. Treatment of the liquid before entry to the evaporator, as in the case of boiler water, while desirable, is generally too expensive, or introduces other difficulties, *e.g.*, $Ca\ SO_4$ can be completely removed by treatment with sodium carbonate, but great care in handling is required or priming will result. In general, before trying out any of the many agents for preventing scale which continue to be put forward it is necessary to ascertain that they are an economical proposition, and that they will not cause corrosion, priming or other ill effects to the evaporator or made water.

Cracking the scale by a sudden change of temperature is often effective, some coils, notably Weir's, being specially designed in the form of an Archimedean spiral with this in view, while others not so designed respond to the treatment equally well. Distortion of the heating surfaces in this way is, of course, of no effect with soft scales, but these can be scraped off without difficulty.

In removing hard scale greater care than is sometimes observed should be given to the chipping of the coils. Hammering should be avoided as much as possible and the use of special hammers scraped to a radius somewhat greater than that of the coils is recommended. Burning off is very effective, but discretion is required or damage to the brazing at the coil ends may result. Some distortion and bruising of the surface cannot be entirely avoided, and this should be corrected from time to time by the application of internal hydraulic pressure or other means.

Distillers.—Horizontal distillers are now preferred to vertical ones. They are less subject to leaks, easier to clean and repair, and better suited to the entrainment and removal of large quantities of low pressure air. The last point is of special importance now that reciprocating evaporator pumps have been largely replaced by rotaries, due to the general introduction of turbo or motor driven auxiliaries consequent upon the gradual abolition of saturated steam. Rotary fresh water pumps are not suitable for dealing with a large volume of air, and ejectors with their own sea-cooled condensers are fitted for this purpose as in recent condenser practice. The efficacy of a rotary pump for removing brine against a high vacuum has also been questioned, with the result that a double-ram reciprocating pump driven by worm gearing off the same motor shaft as the fresh water and circulating pumps have been supplied in a number of cases, but provision has been made for their ready replacement by rotaries at a later date if further experience shows this to be desirable. From the point of view of upkeep, rotary evaporator pumps should prove a welcome advance on the reciprocating type.

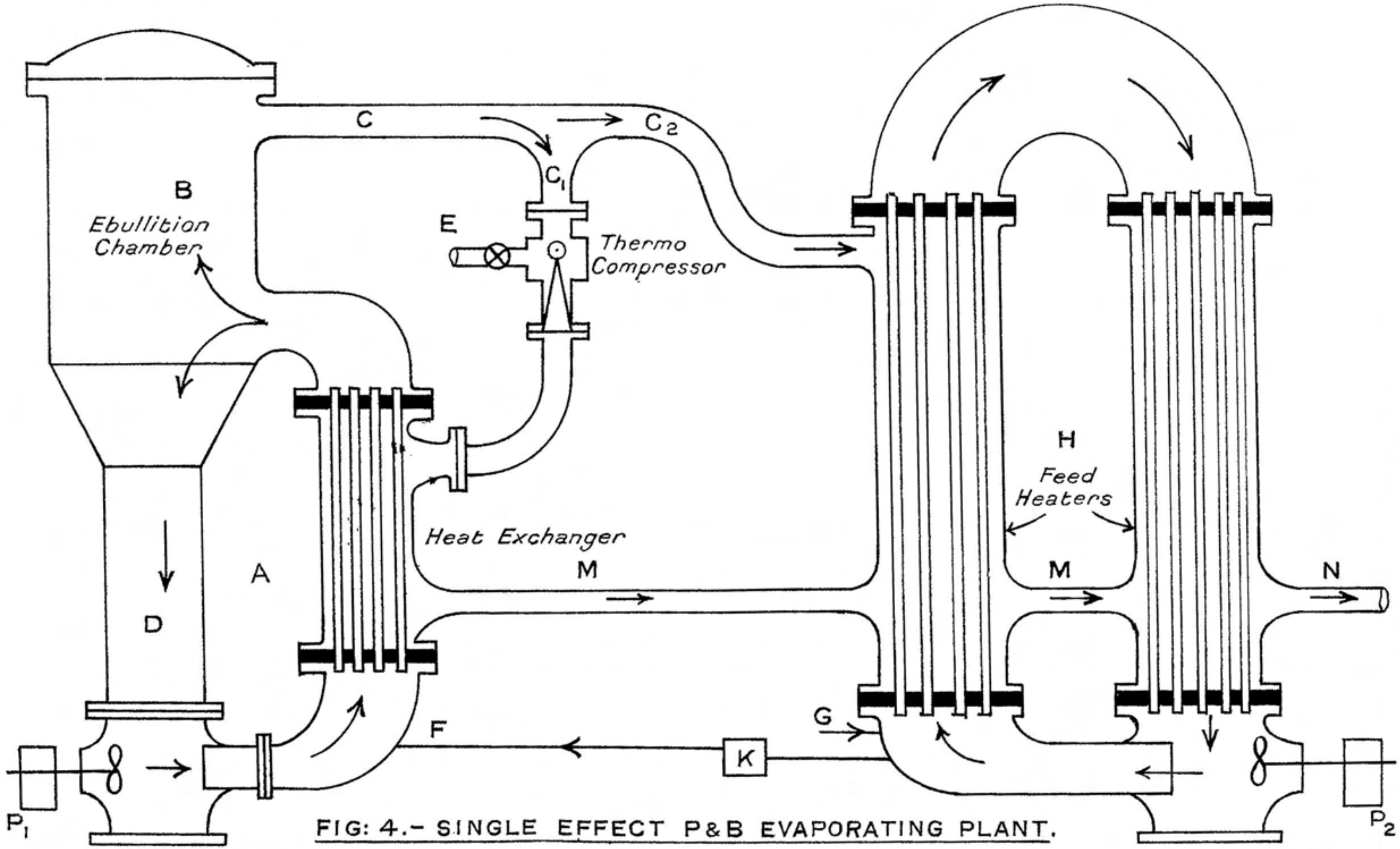

FIG: 4.– SINGLE EFFECT P&B EVAPORATING PLANT.
(Diagrammatic.)

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Malby & Sons, Lith

Face p. 39.

Other forms of Evaporator.—No mention has so far been made of any form of distilling plant except the drowned coil type universally fitted in naval vessels. Commercially, where the object is usually reversed—namely, the concentration of a solution into the solid or viscous state by evaporation of the solvent—the apparatus assumes numerous different forms in response to the demands of the various industries. These are outside the scope of this article, but two sea water evaporators other than those with drowned coils may be mentioned, namely the "film" type and the "P. and B."

In the "film" type, which is favoured in America, the salt-water feed enters the shell at a point above the tube nest and is discharged over a perforated distribution plate. From this plate the water descends in a rain of drops over the tube nest. Part of each drop evaporates and the rest of the drop is said to wash the salt remaining from the evaporation off the tubes down to the bottom of the shell, where the level is kept just above the lower row of tubes. At each effect a pump draws water from the bottom of the shell and discharges part of it back again into the point above the tube nest, and the remainder to the next effect or, in the case of the last effect, to the sea. With this method of circulation "flash" evaporation takes place, and it is claimed that the high proportion of "rain" to vapour formed during any one passage of the coils prevents the formation of scale to any appreciable extent, a result probably assisted by the fact that the brine is finally discharged at a density not exceeding $1 \cdot 5/32$.

The other type deserving notice is that developed by MM. Prache and Bouillon and commonly known as the "P. and B." evaporator, a few sets of which have been installed in H.M. Dockyards.

The distinctive feature of the design is that a portion of the vapour from the evaporator is drawn off and forced by compression into the heating coils. The idea is an old one, piston, turbo and injector compressors having been tried at various times, and the success of MM. Prache and Bouillon's plant is mainly due to the great advance their so-called thermo-compressor shows over the former attempts. The details of the thermo-compressor are closely kept, but in effect it is simply an injector, the vapour being entrained and increased in temperature and pressure by a supply of live steam; the combined product then passing on into the heating coils. Fig. 4 shows diagrammatically the single effect form of the plant; multiple effects are also made. A and H are straight-tube heat exchanges, B a large ebullition chamber with a vapour pipe, C, and a brine return pipe, D. P_1 is a propeller, driven by an electric motor, for circulating the brine through the tubes of A. The brine, during its passage through A, receives heat from the combined vapour, C_1, and live steam, E coming from the thermo-compressor, and on reaching the top of the tubes the rise in temperature, combined with the reduction in head, is such that self-vapourisation occurs as soon as it passes into the ebullition chamber, where the pressure is slightly lower. The vapour thus flashed off passes away through C, while the unvapourised brine drops down through D and is recirculated, together with the necessary quantity of new feed-water entering at F. The portion of the vapour not entrained by the thermo-compressor passes on through C_2 to the feed heaters (or heat exchangers) H. Sea water is circulated through these two heaters by another motor-driven propeller, P_2. The raw supply enters at G and, when heated, passes away to F through a decanting vessel, K. The vapour from C_1 enters the left-hand heater, flows downwards outside the tubes and is partially condensed. This condensate, together with that from A, passes by pipe, M, to the right-hand heater, where the uncondensed portion rises, gives up its heat to the feed-water and drains back to join the rest of the condensate passing away through N to the storage tanks or wherever the made water may be required.

These evaporators are designed for very low pressures and small differences of temperature, the thermal conditions being, very roughly, as follows :—

In the ebullition chamber, B, the vapour is at atmospheric pressure and 212° F. About 1·75 lbs. of this vapour for every pound of live steam supplied at E is drawn off and raised in the thermo-compressor to about 5 lbs. gauge and 228° F., the live steam being correspondingly depressed. About 2·75 lbs. of steam at 228° F. and 5 lbs. gauge therefore enters A for every pound of live steam supplied and converts an approximately equal quantity of brine into vapour at a slightly lower temperature and pressure. Thus the quantity of vapour passing away to the feed heaters H will be $2 \cdot 75 - 1 \cdot 75$ (entrained by compressor) $= 1$ lb., and the total quantity of made water at N will be 2·75 lbs. from A 1 lb. from $H = 3 \cdot 75$ lbs. for every pound of live steam supplied. On actual test this figure is usually found to be about 3 lbs., rising in the case of a double-effect plant to 5 lbs.

Special arrangements (not shown) are provided for continuous brining by drawing off a proportion of the brine in D.

Scaling, it is claimed, is almost entirely eliminated by the turbulence of the brine which is pumped through the tubes of A at a speed above the critical. In the case of very hard waters, however, a small quantity of sand is circulated as an abrasive. As might be expected, the propellers E and J require periodical renewal, but they are not expensive. The durability of the heat-exchanger tubes when an abrasive is continuously used has yet to be proved.

The plants are bulky and somewhat unsuitable for ships' use in other respects, while for the production of cooking and drinking water they are open to the objection that part of the made water is derived direct from the boiler steam and the whole is at a very high temperature. The production ratio, however, is remarkable and the plants are, without doubt, extremely suitable for treating the feed-water for the water tube boilers of modern power stations and for supplying boiler water to ships.