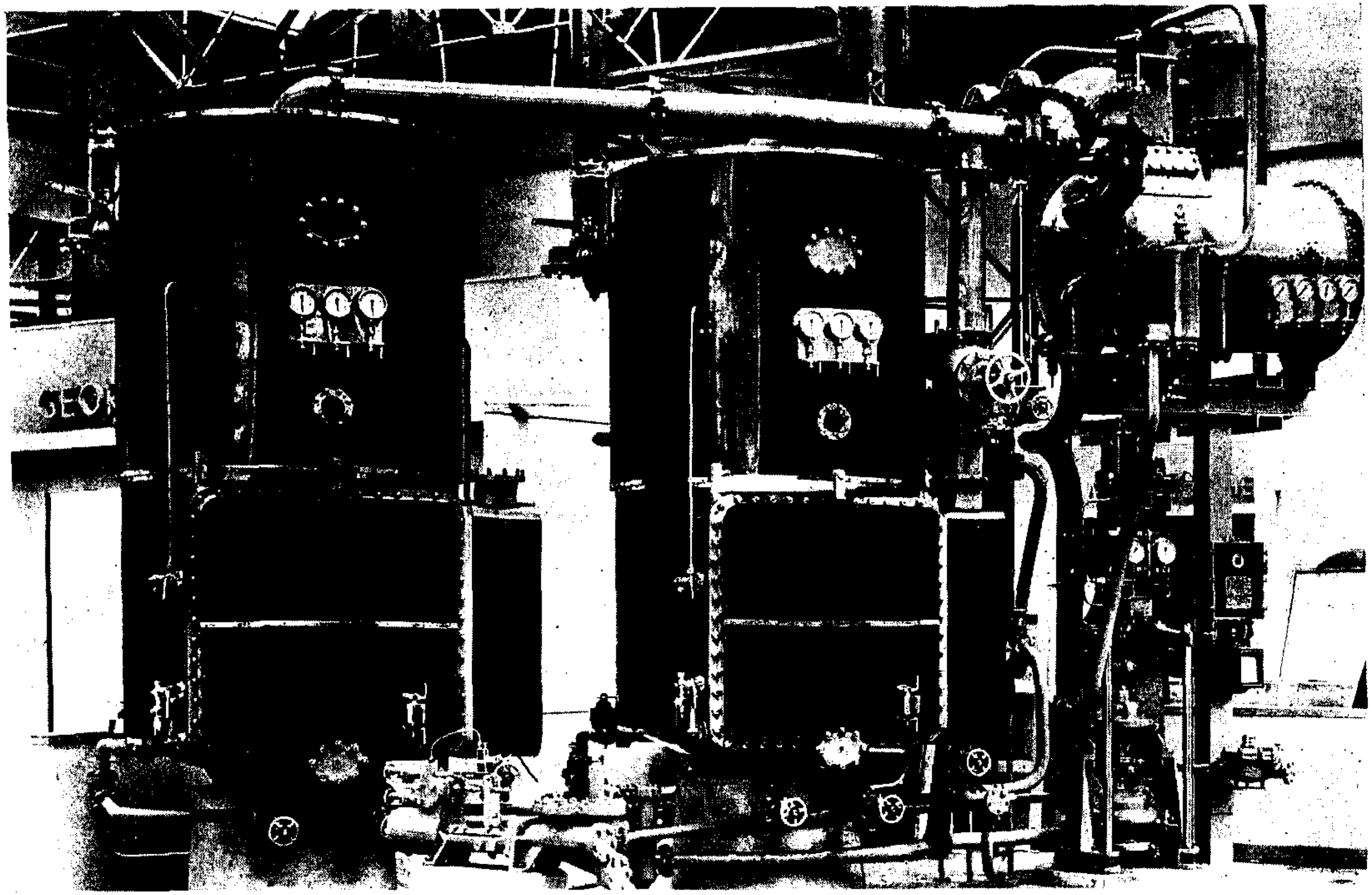


180 Ton/Day Distilling Plant erected at works of Messrs. Weirs prior to installation in a King George V Class Battleship

DISTILLING PLANTS FOR H.M. SHIPS

Part I of this article summarizes the recent developments in the production of distilling plants for H.M. ships and outlines the future programme, and Mr. J. Leicester, R.N.S.S., in Part II, discusses the efforts that have been, and are being made, to overcome the serious problem of scaling in evaporators.

PART I

A GENERAL REVIEW

by

COMMANDER (E) J. D. FARROW, O.B.E., R.N.

Engineer-in-Chief's Department

For many years the distilling plants fitted in H.M. ships have conformed, in general, to a standard design manufactured, with relatively small differences, by various well-known firms. This design has normally incorporated an evaporator shell fitted with steam coils, a distiller condenser, feed heater drain cooler, a combined pump, and the attendant fittings. There has been little change in the basic design for the last twenty years with the exception of such items as improved types of feed regulators, coil attachments, reduced steam pressures, etc.

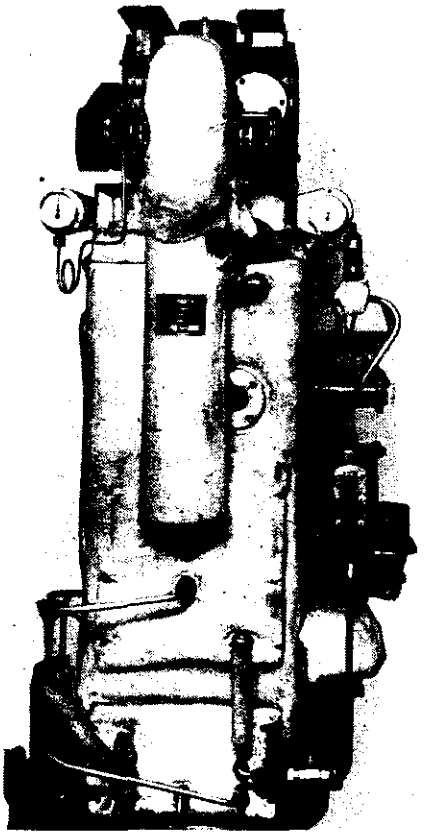
The need for increased distilling plant output in H.M. ships has been accentuated in recent years by the demand for improved amenities, and attention has again been turned, firstly, to the establishment of an experimental station in which work can be carried out on typical distilling plants, as now fitted in H.M. ships, to enable the best operating conditions to be found, and the latest type of accessories and equipment to be given exhaustive trials, and, secondly, to the production of distilling plants of a new design.

NEW DESIGNS

The Forced Circulation Distilling Plants

Experience with the forced circulation distilling plants in the few ships in which this type of plant has been fitted has so far been disappointing. A brief description and diagram of these plants is given in the article " Compression Distillation " in the *Journal of Naval Engineering*, Vol. II No. 1. One of the main difficulties has been the scaling of the heat exchanger tubes. While considerable progress has been made towards finding a suitable scale inhibitor for this particular application there is, as yet, no design of plant available which can be said to have overcome this problem sufficiently to warrant the general introduction of this type of plant in H.M. ships.

While these plants are, in general, much simpler to operate and control, once under way, than the more orthodox type, and in some cases are more reliable in operation, the weight and space occupied are still far greater than for an orthodox coil-type distilling plant of equivalent output.



SUBMARINE DISTILLING PLANT

ILLUSTRATION SHOWS PLANT OF INCREASED OUTPUT ERECTED FOR TRIAL AT WORKS OF MESSRS. CAIRD & RAYNER

Vapour Compression Distilling Plants

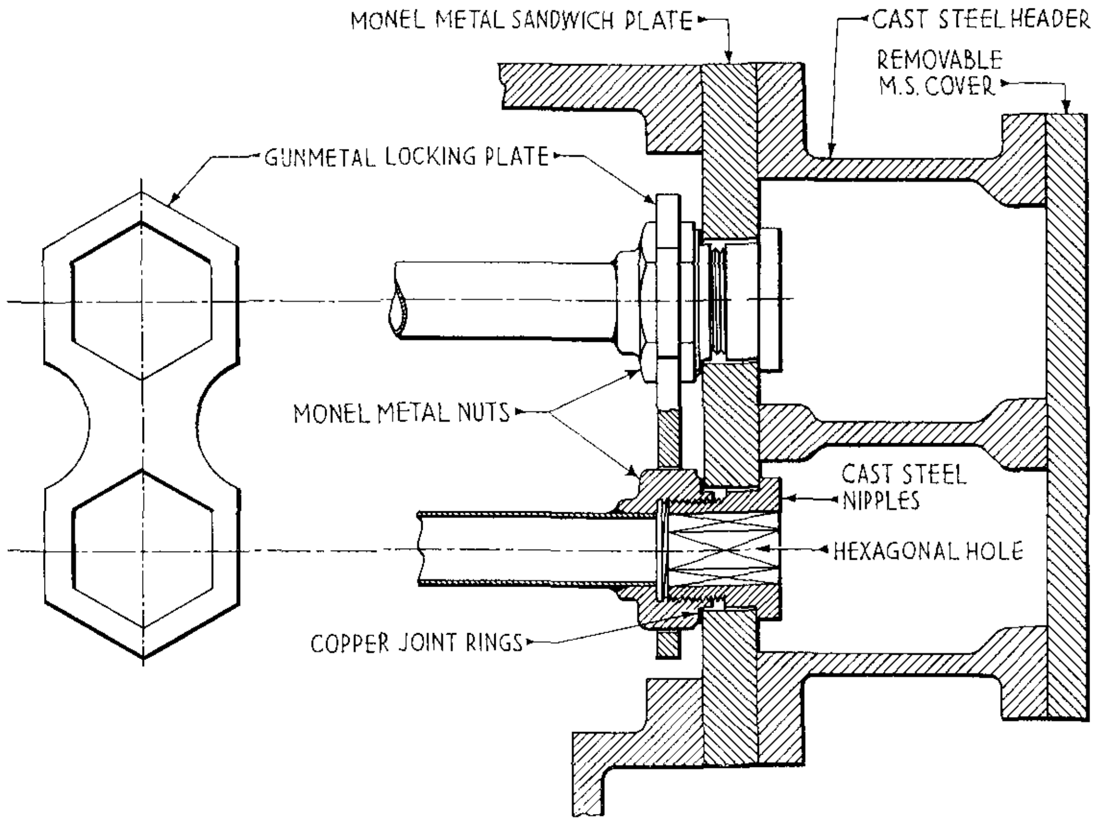
Development contracts have been placed for vapour compression distilling plants of 25 tons/day capacity for small ships and it is hoped that these prototypes may soon be ready for their first trials. A general description of this type of plant and the principles involved are included in the article " Compression Distillation " referred to already. While a Lysholm compressor is being used for the first two prototypes, it has been decided to develop a centrifugal compressor at the same time, as an alternative for trial purposes.

New Design for Small Ships

Design contracts have been placed with a number of firms for the design of a compact light-weight and economical distilling plant for use, in the first instance, in small ships. It is intended that this shall form the basis of the future design for medium and large size plants. In this contract firms were given as free a hand as possible, and the *Statement of Requirements*—with the exception of one or two essential items—was more in the nature of guidance to the manufacturers.

Submarine Distilling Plants

A submarine distilling plant of considerably larger capacity than those at present in service is just completing its trials at the maker's works. A device has recently been added to this plant while on trials, to enable it to run more satisfactorily under " snort " conditions. The results obtained with this device have been most promising and it is hoped to fit it for trial to an existing submarine plant in service in the near future.



LATEST METHOD OF COIL ATTACHMENT
ILLUSTRATING USE OF MONEL SANDWICH PLATE
FOR PROTECTION OF CAST STEEL HEADER

Miscellaneous items

Among the many items to which manufacturers have been asked to pay special attention are :—

(i) Increased economy combined with reduction in the weight and space occupied by the plant.

(ii) Improved methods of securing coils to evaporator headers to ensure easier coil removal.

(iii) Improved baffle design.

(iv) Improved accessibility of strainers and brine pipes.

(v) Separate evaporator pumps of improved design.

(vi) Improved type of feed regulator.

(vii) Reduction in the height and diameter of the evaporator shell in the conventional design of plant.

(viii) Provision of the maximum size doors for scale removal, and increasing the size of blow downs.

(ix) Provision of electric pumps in lieu of steam for injecting the scale inhibitor.

(x) Provision of coil jigs to facilitate stowage and resetting after cleaning coils.

OTHER DEVELOPMENTS

Continuous Reading Brine Density Gauge

A continuous reading brine density gauge which gives an instant and reliable reading under all conditions normally met with afloat, has been developed by the Admiralty Materials Laboratory, Holton Heath, and it is hoped to arrange a trial of this gauge in one of H.M. ships very shortly. If the small difficulties of installation can be satisfactorily overcome this gauge should fill an age-old want and do much to help the operators maintain the brine continuously at the correct density.

Distiller Condensers

Distiller condensers as previously supplied were normally designed to cool the condensate to 120°F. in older ships and to 100°F. in later ones with the circulating water at 85°F.

In order to reduce the temperature of the made water and also the size and weight of distiller condensers in later designs, small after coolers are being fitted to cool the distillate further to 90°F. under the worst conditions.

Output

It has now been decided that all future plants are to be specified for a guaranteed output which must be obtainable after 500 hours' running, making due allowance for scaling.

Control of Plant

It is intended to arrange for all future plants to be as easy to operate as possible and it is now specified that all controls, gauges, etc., should be centrally mounted in a convenient position for the operator. This is not the case in many existing installations.

In addition, considerably more gauges and thermometer pockets are being provided. Flow meters are also being specified and it is hoped to obtain more accurate models.

DISTILLING PLANTS NOW IN SERVICE

It is clear that neither the vapour compression distilling plant nor a new design, can be ready for fitting in H.M. ships for some little time and also there may be further unavoidable delays in establishing the proposed experimental station as a going concern. It is therefore most necessary to turn attention to any method by which the performance of plants at present in service or under construction can be improved.

Shells and Distiller Condensers

Many plants now fitted in ships have steel evaporator shells and distiller condensers : others have cast iron shells. It is the intention to replace such plants (steel first) as and when the non-ferrous shells now on order become available.

Combined Evaporator Pumps

Experience has shown that the combined centrifugal brine, circulating and fresh water pump has not proved as satisfactory as had been hoped and, in future, pumps for orthodox designs will be supplied as two separate units ;

the brine and circulating pump will be one unit and the fresh water and air pump the other.

Coil Headers and Steam Supply to Coils

A number of ships are at present fitted with evaporator headers made of cast steel, this material being necessary on account of superheated steam being used in the plants in question, and it has been found that severe corrosion, aggravated by the high temperatures involved, is taking place on the face of these headers where they are exposed to the brine.

The method of repair that is being adopted is to clean the face of the existing header and fit a monel metal " sandwich piece " of $\frac{7}{8}$-in. in thickness between the header and the shell and fitting new securing bolts and coil ends where applicable. These " sandwich pieces " are however not to be fitted where the shell is also made of steel. It is not expected that superheated steam will have to be used in future distilling plants and this contingency will not therefore arise. It is hoped to be able to arrange for an absolutely steady supply of saturated steam, at approx. 8 lb/sq. in. pressure, to all distilling plants of the future, by taking the supply from a suitable position on the steam system, the plants being designed accordingly.

OPERATION OF EXISTING PLANTS

For a more comprehensive treatment of the subject attention is invited to B.R.1333—*The Distilling Plant : Theory and Operation*, but the following notes refer to some of the more important points in the operation of distilling plants of the type at present fitted in H.M. ships :—

Scale Prevention (see also Part II)

Investigations have been carried out over a long period in an endeavour to improve on the present treatment of the sea-water feed to evaporators, and to overcome the choking of brine systems and pump impellers, which has been encountered from time to time when using starch and boiler compound.

It is hoped to introduce a new chemical, to be known as " Admiralty Evaporator Compound " to take the place of the mixture of starch and boiler compound at present in use. Full-scale trials carried out at sea have been most satisfactory so far and well over 4,000 hours' running without changing coils has been reported. It is anticipated that continuous running can be obtained when using this compound correctly subject, of course, to no mechanical breakdowns.

Output

It should be noted that the rated output of the distilling plants at present in service is that obtainable with clean coils under the designed conditions. If trouble-free and continuous running without frequent coil-changing is to be obtained with these plants it is essential to run the plants at approximately 70% of their *rated* output. It may be possible to increase this to about 80% when using Admiralty Evaporator Compound.

Steam Pressures and Temperatures

Since scale is the main cause of difficulties with distilling plants it is important to maintain conditions at the heating surfaces which are least conducive to its formation.

Steam pressures and temperatures should be kept as low as possible and not allowed to fluctuate. If the coil steam valve is set at an opening to suit the conditions with clean coils, this setting should not normally require any adjustment afterwards, the steam pressure rising automatically as scale forms on the coils due to the gradual reduction of the heat transfer coefficient.

The results reported when using an orifice plate in the steam supply have been very satisfactory and this method is strongly recommended.

When using a scale inhibitor the coil steam pressure will rise to a certain value and should then remain constant for a long period, provided the 24-hourly blowing-down procedure is strictly carried out. It is however appreciated that some difficulty is often experienced when using closed exhaust steam due to the wide variations in temperature which are likely to be met. Also the variations in closed exhaust steam pressure when ships are manoeuvring will at times necessitate reverting to live steam working until steady conditions return.

Coil drain valve settings should also be left constant after initial adjustment in conjunction with the coil steam valve or orifice plate.

Brine densities should be kept constant and 20 degrees is recommended provided satisfactory operation can be obtained under these conditions with plants as at present fitted. B.R. 1333.2.15(c) refers.

The evaporator shell vacuum should always be maintained as high as possible provided it is not allowed to exceed the design value of 20 inches of mercury, which is necessary to ensure that the water reaches the required temperature of 160°F. for sterility.

In some ships it may be found essential to maintain a slightly reduced shell vacuum, due to the coil steam pressure required to pass the coil drain into the drain cooler, without waterlogging the bottom evaporator coils.

Combined Pump Motors

Difficulty has been experienced in certain ships with overloading of the combined pump motors, with consequent damage to the commutators. In some ships this has been overcome by reducing the motor speeds, suitable shims being fitted under the pole shoes to increase the field strength. In other ships valves have been fitted between the circulating water pump discharge and the distiller circulating water inlet to reduce the circulating water pump output and power without increasing the pressure in the distiller.

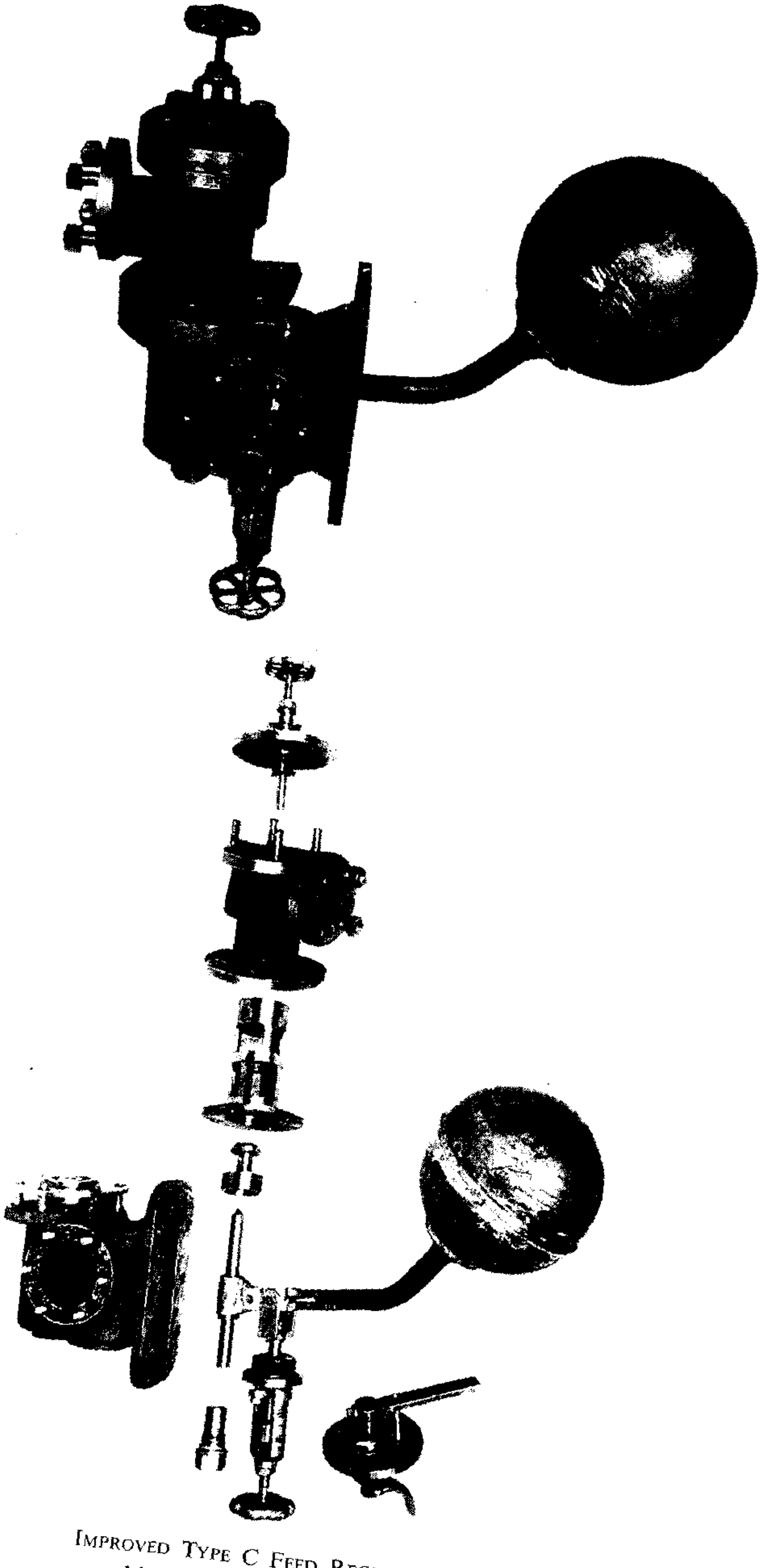
In ships where neither of these modifications have been carried out, it is important to ensure that the setting on the spring-loaded circulating water discharge valve should be set to the designed figure of 25 lb/sq. in. (gauge).

Scale Inhibitor Injection Pumps

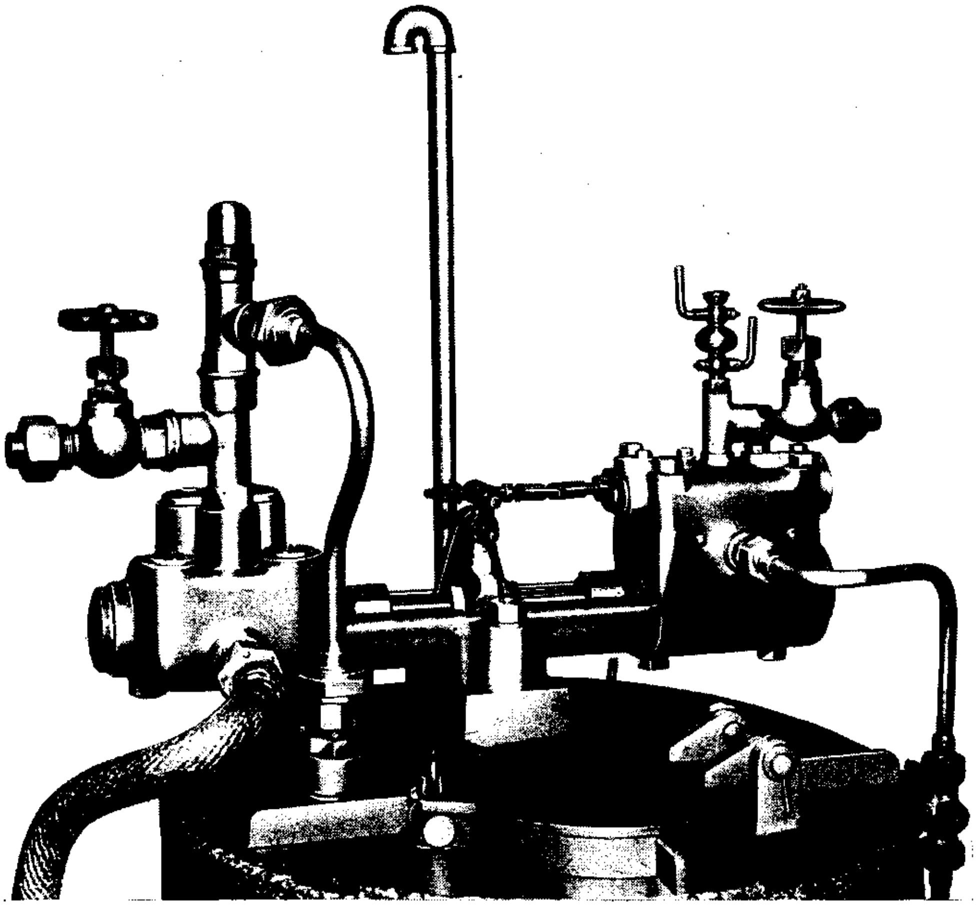
In some ships it has been found difficult to keep the scale-inhibitor injection pumps running steadily owing to water-logging of the steam supply line caused by inadequate drainage arrangement.

It is most important, if scale inhibition is to be really successful, that the mixture be injected continuously whilst the plant is in operation. It is intended to replace the steam reciprocating pumps by small electric pumps, though it will be some time before these can be made available.

The control of the injection of a scale inhibitor should not be carried out by varying the speed of the pump to suit requirements, but by means of the fine control valve or orifice if fitted, and the pump should be set to run at a constant speed. If fine control cannot be obtained with the valve as fitted,



Improved Type C Feed Regulator
Messrs. Caird & Rayner



SCALE INHIBITOR INJECTION EQUIPMENT
AS FITTED TO PLANTS OF MESSRS WEIRS MANUFACTURE

it is suggested that it be modified as shown on page 83 of *Journal of Naval Engineering*, Vol. I, No. 4.

Feed Regulators

It has often been found necessary in older ships to by-pass the feed regulators owing to choking with salt or starch. Some of the latest designs have been found much more satisfactory and arrangements have been made to replace the older types in a number of instances. General replacement is not yet possible and will in any case depend on the result of reports from ships so fitted.

Brine Systems

In ships fitted with steel evaporators the brine suction may be found welded direct to the shell. This means that in the event of a blockage it is impossible to remove the pipe for cleaning. In some such cases the brine suctions have been successfully modified so that suction is taken from the centre of the hand-hole door at the bottom of the evaporator. In the latest designs the complete brine suction pipe can now be withdrawn without the necessity of removing the main door or coils, due allowance being made for scaling.

Baffles

The importance of keeping baffle drains clear of scale cannot be too highly stressed since these units depend largely on the efficiency of the drains for correct separation of the entrained drops of salt water in the made vapour.

PART II

SCALING IN SHIPS' EVAPORATORS

by

J. LEICESTER, R.N.S.S.

Admiralty Materials Laboratory, Department of Aeronautical and Engineering Research

Scale formation in evaporators of ships' distilling plants reduces heat transfer and results in a rapid decrease in the output of the plant. This reduction may have serious effects on fuel consumption, and indirectly on the fighting efficiency of a ship. Under conditions where untreated sea-water is used, it is common for an evaporator to suffer a drop in efficiency (in terms of heat transfer) of approximately 60% after 900 hours' steaming. This represents a reduction in overall heat transfer from 1,050 to 260 British Thermal Units/square foot/°F. temperature difference/hour. Scale on the heating surface is very hard and is firmly bonded to the metal surface ; examination indicates a direct key between the magnesium in the inner scale layers and the copper of the heating coil. An additional trouble with untreated feed water is the rapid scaling up of the auxiliaries with resultant expenditure of manpower for replacement and cleaning.

The direct removal of the salts in sea-water by chemical means is impossible due to the weights of reagents required. On an average one ton of sea-water contains approximately 70 lb of dissolved salts consisting almost entirely of the chlorides, sulphates and bicarbonates of sodium, calcium and magnesium. Whilst the major solid compound present, sodium chloride, is very soluble and relatively harmless when considering hard scale formation, the remaining calcium and magnesium salts produce scale due to the formation of compounds which are very insoluble under conditions present during brine evaporation. Scales formed under such conditions consist mainly of calcium carbonate, magnesium hydroxide, and calcium sulphate according to the well-known chemical reactions outlined below. The proportion in which these compounds appear in the scales, their crystalline form, texture, hardness, and resistance to the transfer of heat, largely depend upon distilling plant operating conditions and may exhibit considerable variations. The main chemical reactions occurring during sea-water concentration and evaporation are as follows :—

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O \quad \text{.......(1)}$$

$$Mg(HCO_3)_2 \rightarrow MgCO_3 + CO_2 + H_2O \quad \text{.......(2)}$$

and on prolonged boiling reaction (2) further changes to

$$MgCO_3 + H_2O \rightarrow Mg(OH)_2 + CO_2 \quad \text{.......(3)}$$

Traces of silica are sometimes found combined with the above compounds in the form of complex silicates and small amounts of salts normally soluble under conditions of evaporation are occasionally entrained in the scales. As one evaporator may handle up to 20 tons of sea-water per hour, the weight of precipitate produced from a chemical method of feed treatment would be considerable and its removal difficult. Additions of chemicals like citric acid or acid sodium sulphate will reduce the pH of the brine and largely prevent scaling, as the calcium and magnesium remain in solution as bicarbonates. Treatments based on this principle have proved unsatisfactory because of the excessive weight of reagent that is needed, and also the danger of corrosion to the non-ferrous parts in the evaporator.

DEVELOPMENT OF A FEED TREATMENT TO REDUCE THE FORMATION OF HARD AND ADHERENT SCALE

In the past H.M. ships have used a feed-water treatment involving the continuous addition of corn starch and boiler compound B.C.N.* The U.S. Navy who developed this treatment reported considerable success with it, but results in British ships have been less satisfactory. The difference observed may be partially accounted for by the more stringent density conditions in British naval evaporators, 20°-25° for British ships as compared with 15° for the U.S. Navy. In general, providing perfect mixing of the compound takes place, the operating conditions are improved. An evaporator, similar to the size of the one last referred to, should continue to function for 1500 to 2000 hours before efficiency has dropped to the point where cleaning has become necessary. However, it is difficult to solubilise the starch satisfactorily, and poor mixing may result in a lower efficiency than that obtained with no treatment at all. The character of the scale formed is modified, producing a soft crumbly deposit which is thicker than that obtained with untreated feeds. It is not brittle enough to break away from the coils even under conditions of extreme mechanical flexing. The result is lower heat transfer and often a gumming up and sticking of the auxiliaries due to the semi-hydrolised starch in the system.

As a result of tests in this laboratory, it was suggested that the addition of small quantities of surface active agents alone, or admixed with threshold quantities of a complex phosphate, to the sea-water feed would change the character of the deposit and prevent the deposition of hard and adherent scale. Most of the work has been done with one dispersing agent, Belloid T.D., the sodium salt of di-naphthyl methane di-sulphonic acid. It was hoped that this material would be adsorbed on both the metal and the particles of the precipitate, and would facilitate the discharge of the latter as a fine suspension. This expectation has been realized in both laboratory and full-scale experiments. Its effects have been further improved by the admixture of small quantities of tetra sodium pyrophosphate, sodium hexametaphosphate, or sodium tripolyphosphate ; the latter material being the most satisfactory. The quantities of reagent required are small, 0.003% by weight of the sea-water, or approximately one pound of reagent to 20 tons of sea-water treated. It is therefore possible to stow the material required for 6 months' operation in a comparatively small space, and the cost is low, increasing the cost of distilled water by approximately 1½d. per ton. The material is easily mixed, and can be dissolved in cold water, and has a beneficial effect in preventing the scaling up of auxiliaries. The use of Belloid in evaporators has indicated that the rate of the initial growth of the scale is not substantially changed, but that the continuous decrease in efficiency of the evaporators is greatly reduced. The initial bonding of the scale to the copper tube is prevented and the scale deposit is friable and less adherent. Its physical structure and lower adherence allow it to lift and crack away from the coil under the conditions of operation. This intermittent lifting, cracking, and breaking away of the deposit allows an equilibrium to be reached so that the scale removed is equal to the new material deposited.

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* *Note:* Composition of B.C.N. compound :

Sodium carbonate	39%
Di-sodium hydrogen phosphate.. ..	48%
Starch	13%

FIG. 1

Figure 1 illustrates the cracking and shows the coil surfaces and the bottom of the evaporator used for the trials referred to above after 4,700 hours' operation, using a feed treatment of 12 oz of Belloid T.D./20 tons of sea-water feed. Confirmation of the value of this treatment has been obtained from the Merchant Navy ; here evaporators often operate for long periods without attention and under varied conditions. In all cases, however, considerable improvement has been obtained by the use of Belloid T.D.

Brief reference must also be made to the prevention of scaling in the heaters of various forced circulation type distilling plants such as that fitted in H.M.S. *Vanguard*. The fundamental difficulty of the problem was that in these plants nearly boiling brine is circulated through $\frac{7}{8}$ in internal diameter tubes with steam on the outside. The brine passing through the heater at approximately 218°F. is prevented from boiling by a positive pressure head. The scale in this case is mainly magnesium hydroxide which is deposited in a hard and adherent form. The flow through the tube is rapidly reduced due to the reduction in effective diameter as precipitation proceeds. Very little mechanical flexing occurs in these tubes during running and the shedding of the scale in large flakes tends to obstruct the tube bore. Consequently this type of plant presents a much more difficult problem than the more conventional design. A treatment by the threshold method, a mixture of 0.003% by weight of Belloid T.D. and 0.0005% sodium hexametaphosphate or sodium tripolyphosphate, was, however, successful. The action of the phosphate prevents the precipitation of hard scale, and brings it down in the form of a sludge while the Belloid T.D. ensures that this sludge is easily wetted and dispersed on water washing. Pilot plant trials have indicated that if a heater tube containing a deposit from 300 hours' continuous running with this treatment is filled with distilled water which is then boiled and discharged to waste, the tube surface is left in a perfectly clean condition.

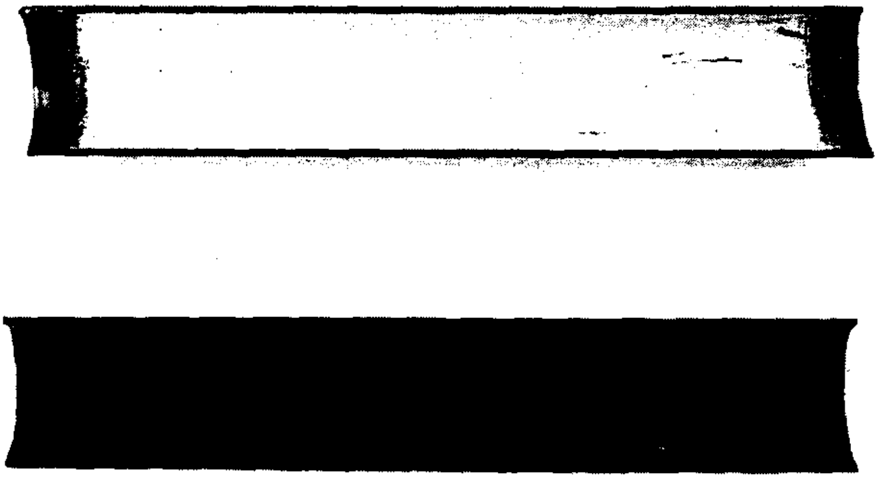

Fig. 2

Fig. 2 illustrates the cleaning of one heater tube by this method. For comparison, the tube before washing is shown in the photograph above. Very encouraging results were obtained using this treatment in H.M.S. *Vanguard* during a recent cruise, and also in a similar type of distilling plant installed in H.M.S. *Glasgow*.

DENSITY CONTROL AS AN AID TO THE REDUCTION OF SCALING

The standard practice in H.M. ships is to operate evaporators with a brine density of from 20°-25° Admiralty. This density was adopted as the best compromize between operating efficiency and rate of scalding. Reduction of the density to 15° Admiralty would reduce scale formation, but would involve a larger brine pump capacity, and the discharge of increased volume of brine to waste. The consequent loss of heated brine reduces the thermal efficiency of the plant in terms of the quantity of the fuel burned.

The density control is very important ; the present density, 25° Admiralty, being critical. A rise to 28°, if only for short periods, results in the deposition of a very hard calcium sulphate deposit. An instrument has been designed for the continuous indication of brine density, and it should prove of value in maintaining constant density and eliminate the present frequent checks with a hydrometer. The instrument is rugged, immune to ships' vibration and is capable of recording a change of density to one part in a thousand. The meter and density tube (see Fig. 4) works on the principle of a radio frequency measurement in which a change in the density of a liquid causes a change in the " Q " value of the coil of an oscillatory circuit, when a column of the liquid under test is capacitatively coupled in parallel with the circuit.

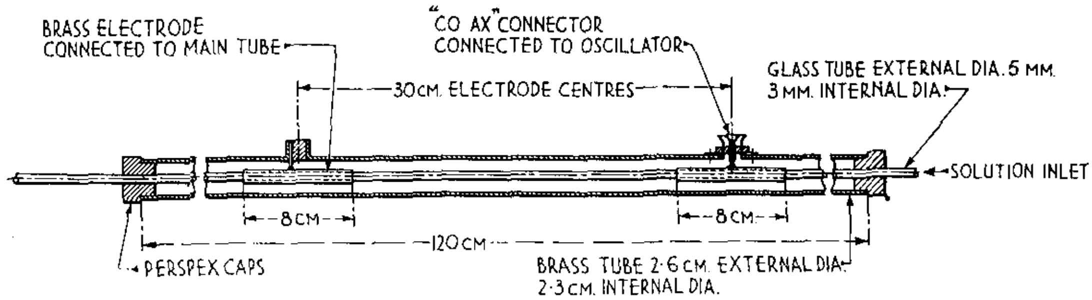

FIG. 3

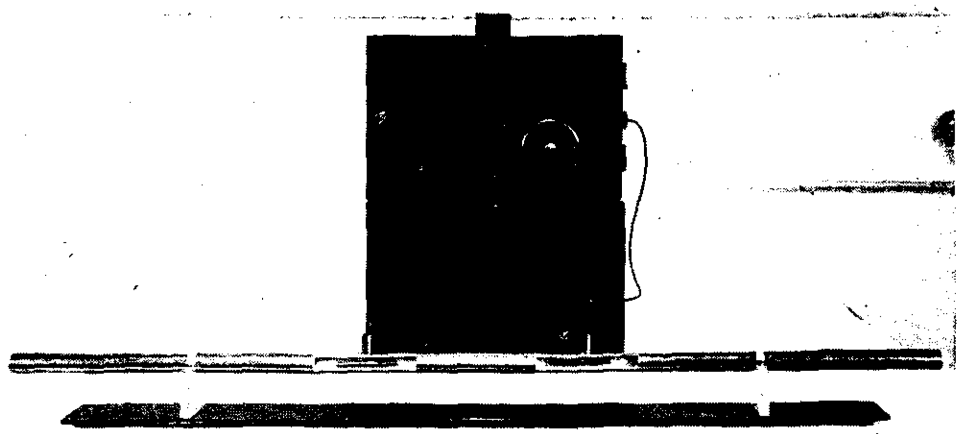

FIG. 4

Under such conditions the variation in anode current of the oscillating valve is linear with respect to the density of the solution under test. The principle of the " Q " method applied to the measurement of conductivity, or in this case density, of an electrolyte makes possible the avoidance of immersed electrodes (see Fig. 3) with the attendant scaling of the metal surfaces. The instrument can be temperature-compensated enabling calibration of the indicator to be made to any convenient reference temperature. A prototype instrument is now awaiting Service trials.

SCALING PROBLEMS IN FUTURE DESIGN

Future distilling plant problems will largely be determined by new designs and equipment, but it is anticipated that our present knowledge will enable any scaling problems connected with these new designs to be reduced to a minimum. The use of vapour compression stills in the Navy is under active review, and work on two prototypes is well advanced. Pilot plant experiments are being conducted on scaling in this type of evaporator using a small submarine type vapour compression still. Initial evidence has again confirmed the success of Belloid T.D. mixtures for its feed water treatment.

Consideration is being given to the subject of submerged combustion. This is an ideal method for the evaporation of solutions producing bad scaling as there is no metal heating surface on which to deposit scale and hinder heat transfer. It appears possible to obtain very high thermal efficiencies with this type of equipment ; but unfortunately experience with it is limited to natural gas as a fuel. The substitution of boiler fuel would present serious difficulties owing to the possibility of incomplete combustion which would lead to flame instability and contamination in the distilled water. The chances of overcoming these difficulties and the possible merits of the system for Naval use are being assessed.