Paper read at the Royal Institution of Naval Architects, on Tuesday, 28 October, 1975

SEA WATER DISTILLERS

A Gilchrist, C.Eng., M.I.Mech.E., M.I.Mar.E.*

The economics of onboard production of fresh water and an increase in its per capita usage by ships' personnel together with the advent of the unmanned machinery space have given impetus to the development of the automatic sea water distiller. The factors governing the choice of plant type for any vessel are briefly discussed. Single effect high vacuum distillers arranged to accept diesel engine jacket cooling water or low pressure bled or exhaust steam as the heating medium are described in detail with emphasis on the automatic control of the vital processes, the ease of remote control and other special features. The design principles of other types of sea water distillers, flash distillation plant and vapour compression distillers are given and typical plant are described. Automatic and remote control are again discussed and comparisons are made of the attainable distillate output/heat input gain ratio. A brief reference is made to scale deposition on the heat transfer surfaces of sea water distillers and associated topics of continuous feed treatment and intermittent acid cleaning. The paper concludes that distillation is the only viable form of desalination and future developments will be the direct result of commercial pressures.

INTRODUCTION

The economics of present day ship operation demand that the maximum possible space be devoted to cargo whether this be dry cargo, bulk cargo, oil or indeed passengers. As a direct consequence of this, the space devoted to water carrying capacity has been greatly reduced with greater reliance being placed on the shipboard production of distilled water from sea water both for machinery and domestic purposes.

In parallel with the reduction in water carrying capacity has come improvements in onboard living conditions and facilities for ships' personnel with attendant increase in the per capita usage of water.

This increasing reliance on shipboard produced water, together with the introduction of the unmanned machinery space, required that the sea water distiller be capable of producing its rated output for long periods with the minimum attention.

To meet these requirements the modern sea water distiller has developed in a number of well defined steps, from a plant that could, with the attention of a skilled operator, produce distilled water of acceptable quality for limited periods between descaling operations to a plant that can reliably produce high quality distilled water for extended periods during fully automatic operation.

TYPES OF PLANT

The choice of plant type for any given vessel will be determined firstly by the type of prime mover fitted, secondly by the made water/heat input gain ratio required and thirdly on the availability or otherwise of a suitable heating medium.

Vessels fitted with diesel engines have no real choice, the only viable plant being the single effect high vacuum submerged tube type utilizing diesel engine cooling water as the heating medium.

For vessels with steam turbine main machinery the plant will operate with low pressure bled or exhaust steam as the heating medium. The choice must be made between the single effect high vacuum submerged tube type and plant operating on the flash principle of varying number of flash stages. The decision must be made as to the required gain ratio dependent on the quantity of bled or exhaust steam available relative to the quantity of distilled water required.

The same plant types must be considered and the decision made on the same reasoning for gas turbine powered vessels where steam is available. Where steam is not available plant of the vapour compression type can operate on an electrical input only.

SINGLE EFFECT SUBMERGED TUBE PLANT

Hot Water Heated

The operating conditions of the single effect high vacuum submerged tube plant utilizing diesel engine jacket cooling water as the heating medium are fairly well defined and a typical heat balance diagram is shown in Fig. 1.

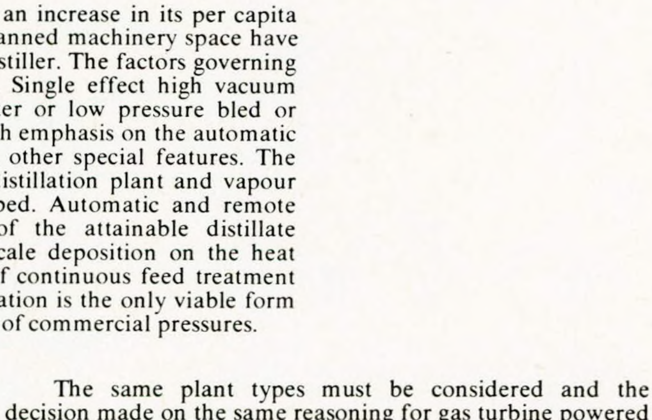

FIG. 1 — *Heat balance, single effect submerged tube, hot water heated*

Plants of this type are generally suitable for a manual start up and shut down, but must be capable of fully automatic running during normal operating conditions. A sea water distiller including the necessary controls is shown diagrammatically in Fig. 2.

The plant comprises an upper, or vapour, shell housing a sea water cooled hairpin tube distilling condenser and two wire mesh demister type vapour separators. The heat input section, which is suspended below the vapour shell, comprises a straight vertical tube heat exchanger suitable for accepting

* Industrial and Marine Division, Weir Pumps Limited.

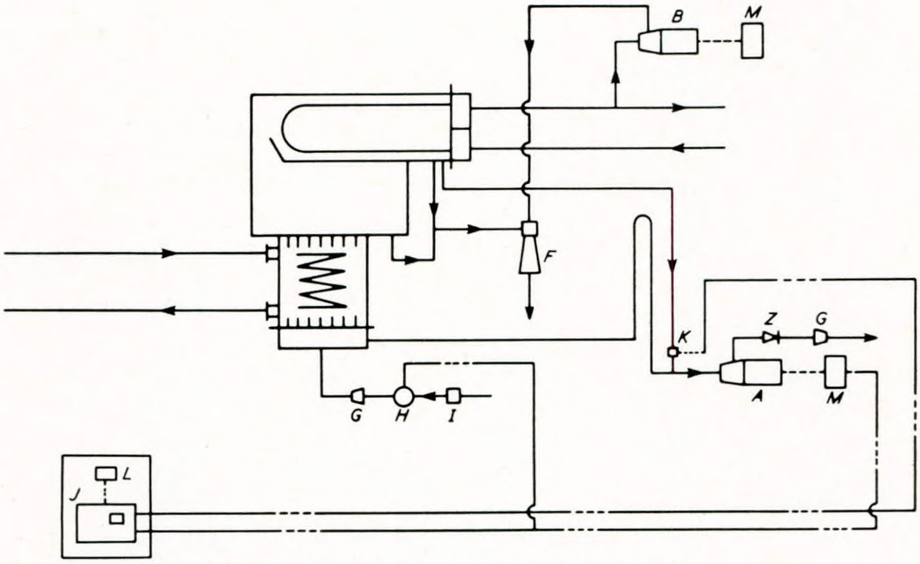

FIG. 2 — *Diagrammatic arrangement single effect submerged tube, hot water heated*

diesel engine jacket cooling water as the heating medium. Internal flow baffles are incorporated in the shell to induce a flow pattern across the outside of the tubes to ensure efficient heat transfer.

Sea water feed is admitted to the sump through a simple variable orifice flow controller which passes a constant pre-determined quantity regardless of upstream pressure, provided the necessary minimum pressure is maintained. A flow indicator is fitted to give both a visual indication of flow and through electrical contacts, an alarm of any low flow condition. A feed strainer is also fitted to protect the flow controller from the ingress of sea weed and other marine debris. After entering the sump the sea water passes once, and once only, upwards through the tubes to the upper shell. Part having been converted to vapour passes through the demisters to the distilling condenser and the remainder, being concentrated sea water or brine, is extracted by a water operated ejector which has been specially developed to withdraw not only brine but air and non condensable gases from the plant, thus maintaining the high vacuum necessary for satisfactory operation. Operating water is supplied to the ejector at the required pressure by a separate sea water supply pump.

The distilled water, formed by the produced vapour condensing on the outside of the sea water circulated hairpin tubes forming the distilling condenser, is extracted by a distillate pump and discharged through a non-return valve and variable orifice flow controller sized to pass only the rated output of the plant. If, for any reason, the plant is induced to produce an output in excess of the designed output only the rated output of the unit can be discharged and the excess distillate is recycled over the return loops to the sump. As the sea water feed and distillate flow controllers are matched to give a predetermined ratio of sea water feed to distillate, this control system, together with the return loop system, provides automatic control of brine density.

A conductivity meter monitors the quality of distillate being produced and controls its discharge in a unique manner. In this system the conductivity meter controls the running of the distilled water pump through the motor starter. If the distillate is of acceptable quality the pump runs and discharges it to the ship's tanks, if the quality is unacceptable the pump stops and use is again made of the return loop system, in this instance to recycle all of the distillate produced to the sump for re-distillation.

This description of the basic single effect flow cycle is common to all versions of the plant and it is considered that the primary parts and features should be more fully discussed at this point.

Vapour Shell: though some owners still specify non-ferrous materials this vessel is now almost universally fabricated in mild steel plate protected from corrosion on all internal surfaces by a protective coating. Experimental and field proving tests on many epoxy or chlorinated rubber paints have met with varying degrees of success but none has given satisfaction over reasonable periods of time. At best, with careful preparation and application, paint linings have required annual renewal for effective protection. The most satisfactory lining found to date has been natural rubber sheeting which is rolled and bonded to the shot blasted metal before final heat curing. This lining is carried over all external flanges to ensure complete protection and is spark tested to ensure complete bonding and freedom from cracks or even pinholes.

Vapour Separator: the development and use of the demister type vapour separator has been arguably the greatest single factor in improving the overall performance and distillate purity of sea water distillers. Previously the vapour separator, of whichever type, has been an area of great design expertise and indeed some plants still utilize variations of the vane type baffle and flat plate deflector where relatively low quality potable water only is required. Demisters are a matrix of multiple layers of knitted wire and achieve separation by impingement. Vapour passes freely through but water droplets accumulate and ultimately coalesce into drops large enough to break free and drop back against the vapour flow. Material of manufacture can be either monel or polypropylene, experience has shown that correctly fitted demisters of either material give comparable results. Polypropylene is however only suitable for vapour temperatures up to some 70 to 75°C thereafter plastic deformation takes place.

Flow Controllers: several types of constant flow device are available all operating on the variable orifice principle. A simple orifice will pass a greater or lesser quantity with an increase or decrease in upstream pressure, assuming constant downstream pressure. The constant flow device forms an orifice between a seat and a flexible plug which is held firmly in place by upstream pressure. An increase in upstream pressure will compress the plug further into the seat thus reducing the orifice area and conversely a decrease in upstream pressure will allow the plug to reduce its initial compression and increase the orifice area. Thus a variable orifice is presented to the flow and consequently a constant quantity is passed regardless of upstream pressure provided that a minimum pressure of 2·0 bar is maintained at the inlet to the device.

Combined Ejector: a water operated ejector has been developed capable of withdrawing not only brine, including all the sea water passed by the feed controller and all the distilled water recirculated when rejection level is reached, but also the air and non-condensible gases entrained and released by the incoming sea water thus maintaining the high vacuum necessary for the satisfactory operation of the plant. The ratio of operating water to entrained brine of some 30:1 ensures that the brine is so diluted that scaling problems in the brine piping and overboard discharge valve are eliminated. Also eliminated are mechanical problems with air pumps which were largely due to cavitation erosion at very high vacuum during operation in very cold sea water conditions.

Distillate Quality Control: the quality of distillate produced by any sea water distiller is continuously monitored by a conductivity meter. On most plants the water already in the ship's tanks is protected by a system of solenoid operated diverting valves controlled by the conductivity meter. In the system under consideration the conductivity meter controls the running of the distilled water pump through the motor starter. If the distillate being produced is of acceptable quality the pump will run and discharge water to the ship's tanks. If the distillate quality is unacceptable the conductivity meter will indicate an alarm condition and the pump will stop. It will be appreciated that in this condition distilled water is still being produced and with the pump stopped this water will return to the plant sump for re-distillation over a double inverted "U" loop system. The top of each leg is individually vented to the air suction line to prevent a syphon occurring and preventing the pump taking suction on restaring. One obvious advantage of the system is that in the event of valve leakage, and we must accept that eventually valves do leak, the only valve involved is the distillate pump non-return discharge valve. As this valve has at least atmospheric pressure downstream and plant vacuum upstream any leakage must be into the plant. In the case of the solenoid operated diverting valves, with distillate pump discharge pressure upstream and static head only downstream, any leakage must be outwards from the plant with consequent possibility of contamination of water already in the ships tanks.

Brine Density Control: further use is made of the distillate return loop system as part of the brine density control system. Any distiller can, under clean tube conditions, produce considerably in excess of its rated output. If this were allowed to happen with a fixed sea water feed input quantity an unacceptable high brine density could arise with consequent scaling of the heating tube surface. To avoid this condition the distillate discharged from the plant is restricted to the rated plant output with any excess production being returned to the sump over the return loop system to maintain an acceptable brine density. The feed and distillate controllers have a ratio of 2·75:1; should the feed quantity be reduced for any reason the feed flow indicator will give an alarm if the ratio drops to 2:1.

It has already been described how the conductivity meter controls the running of the distilled water pump through the motor starter. Further use is made of this feature by incorporating the contacts of the feed flow indicator in series between the conductivity meter and the distillate pump starter. See Fig. 3. In this way, if an alarm condition exists, the distillate pump will stop and all the distillate being produced will return to the sump over the return loop system to maintain an acceptable brine density until remedial action is taken to reinstate the normal feed quantity.

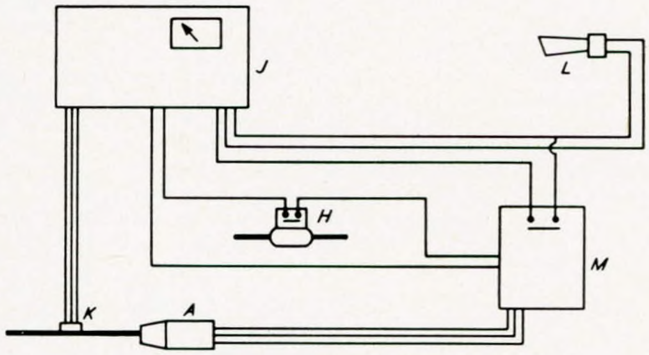

FIG. 3 — *Distillate control circuit, hot water heated distiller*

Remote Control: as previously stated plant of this type are generally arranged for manual start up. It is however a simple matter to arrange for remote start/stop from a single rotary switch and this is shown diagrammatically in Fig. 4. The additional equipment required is a solenoid operated feed supply valve, a solenoid operated vacuum release valve, a heating water inlet thermostat, an orifice and a level switch on the distillate suction line.

The action of the feed valve is purely ON/OFF for start up and shut down. The vacuum release valve can be actuated by either the heating water thermostat or the distillate level switch. If the diesel engine jacket cooling water temperature drops below a predetermined level, either by slowing or stopping the engine, the thermostat will open the vacuum release valve thus reducing the plant vacuum to a level where the heat absorbing capacity of the unit is curtailed to prevent undercooling of the main engine. Conversely if the quantity of heat is greatly in excess of that required for rated output some limitation must be imposed in addition to the output controller. To this end an orifice is fitted in the distilled water

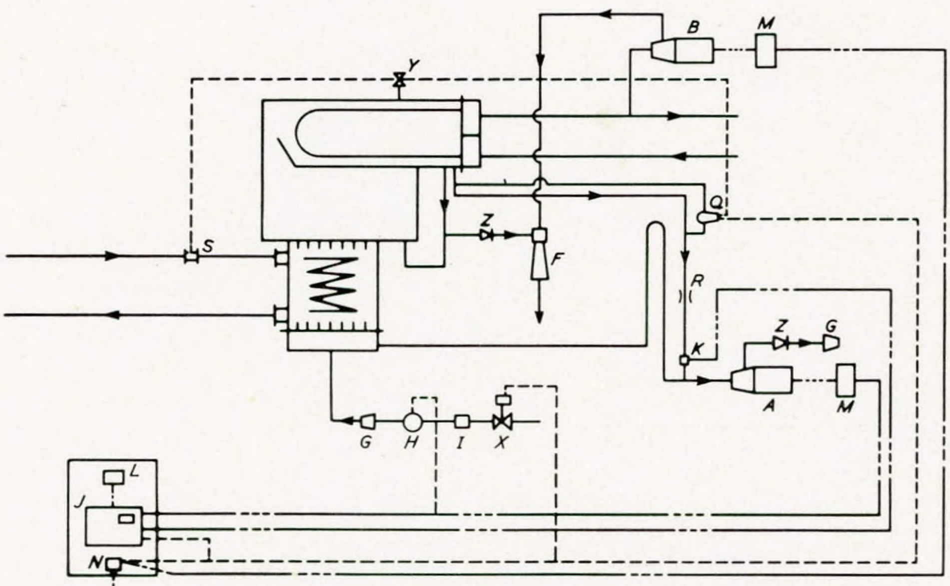

FIG. 4 — *Diagrammatic arrangement (remote control) single effect submerged tube, hot water heated*

pump suction line sized to pass some 25 per cent in excess of rated output. At outputs in excess of this distillate builds up above the orifice until the level switch opens the vacuum release valve to reduce the plant vacuum to a level where the plant output is returned to an acceptable level.

Steam Heated

In most sea water distiller ranges the steam heated plant is usually an adaptation of the hot water heated plant thus using common components to facilitate a rational manufacturing and spares programme.

A single effect high vacuum submerged tube plant utilizing low pressure bled or exhaust steam as the heating medium is shown diagrammatically in Fig. 5. This plant comprises the same vapour shell module containing the distilling condenser tube bundle and demisters. The sea water feed again passes through the feed strainer, flow indicator, and flow controller. The brine and air are extracted by the combined ejector supplied with operating water from the sea water supply pump and the distillate is extracted and discharged by the distilled water pump through the non-return valve and flow controller under the control of the conductivity meter.

Heating Steam Control: where the steam supply pressure is sufficiently high, the simplest and possibly the best method of steam control is by a simple orifice sized to give a critical pressure drop. Unfortunately in the majority of cases this is

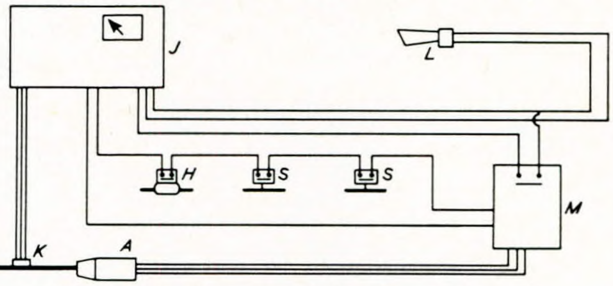

FIG. 6 — *Distillate control circuit, steam heated distiller*

not possible thus requiring an alternative system. A variable orifice flow controller sized to pass the quantity of condensate equivalent to the required steam input to the plant for rated

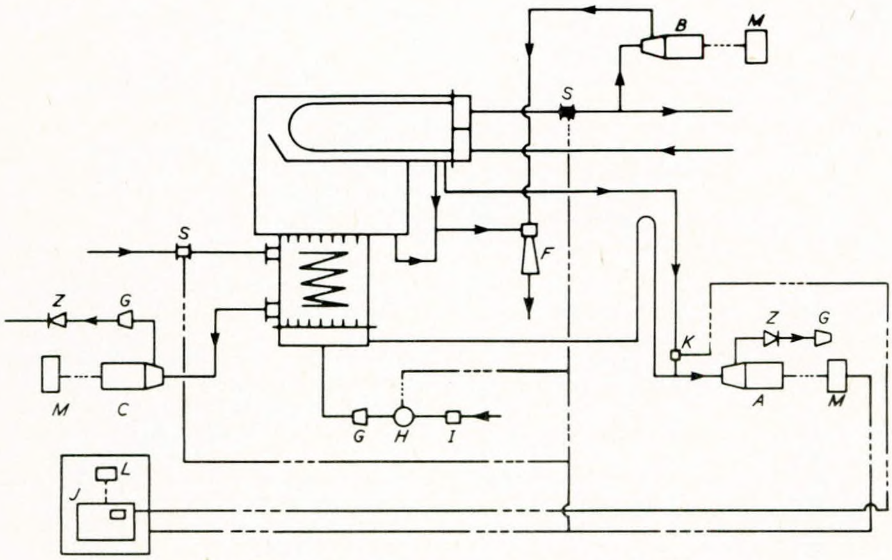

FIG. 5 — *Diagrammatic arrangement, single effect submerged tube, steam heated*

Where this plant differs is that the heat input section which again comprises a straight vertical tube heat exchanger, incorporates a steam baffle to prevent direct impingement of the steam on the tubes, steam lanes to ensure complete dispersal of steam throughout the tube stack and a diaphragm plate to prevent direct access of the steam to the condensate outlet connexion. A pump is fitted to extract the condensate and arranged to discharge to the ship's system through a non-return valve and variable orifice flow controller which limits the quantity of condensate that can be discharged and consequently the quantity of steam that can be admitted to the plant. A steam temperature thermostat is fitted to give an alarm if the steam temperature exceeds a predetermined level. A second temperature thermostat is fitted on the distilling condenser circulating water outlet branch to give alarm on a high temperature condition at this point.

As both temperature thermostats give warning of conditions leading to accelerating scale conditions, the electrical contacts of the thermostats are incorporated together with the contacts of the feed flow indicator between the conductivity meter and distillate pump starter as previously described. Fig. 6.

With the exception of remote control, the features discussed for the hot water plant are valid for the steam heated plant. A separate system of remote control is involved and a heating steam control system is added.

output is fitted on the condensate pump discharge. It will be appreciated that on start up the heat exchange surface is capable of condensing considerably more steam than the discharge controller can pass.

In consequence of this, the level in the shell will rise until a balance is reached between the surface area exposed for the condensation of steam and the quantity of condensate the controller can pass. In this way a constant pressure variable surface system of heating steam control is achieved.

Remote Control: as for the hot water heated plant it is a simple matter to arrange the steam heated plant for remote START/STOP from a single rotary switch. This is shown diagrammatically in Fig. 7. The additional equipment required is a motor driven steam inlet valve, a solenoid operated feed inlet valve, a solenoid operated vacuum release valve, and two vacuum switches.

The action of the steam and feed inlet valves is purely ON/OFF for start up and shut down. The vacuum release valve in this instance is actuated by a vacuum switch set to a predetermined level to reduce a very high vacuum which can be induced during operation in very cold sea temperatures, a condition that can lead to overloading of the demisters due to high vapour specific volumes. The second vacuum switch controls the intermittent running of the ejector sea water supply pump when the plant is in the standby condition. In this condition vacuum is maintained in the plant which serves

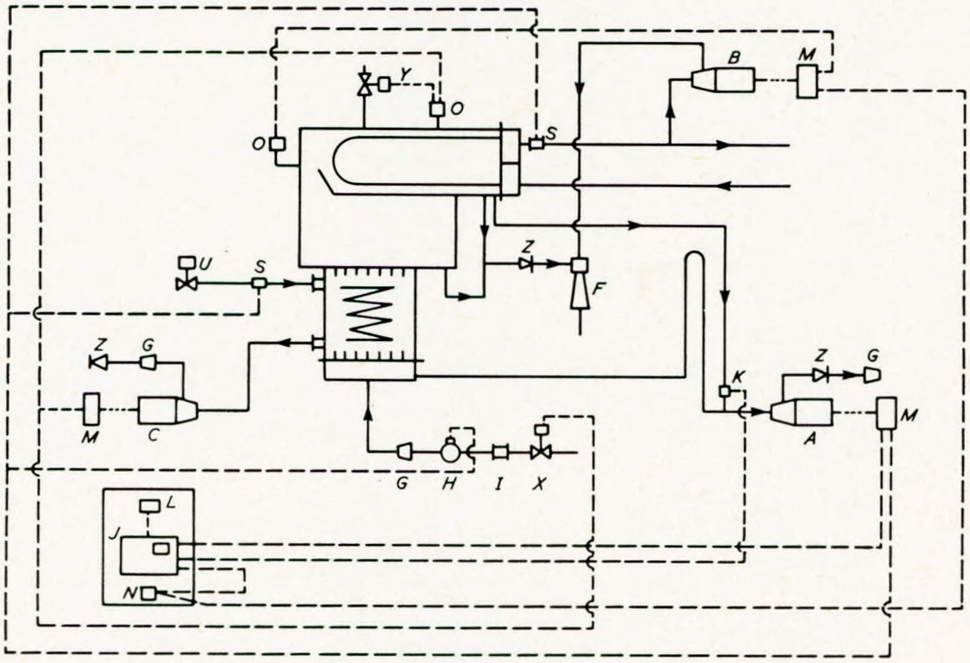

FIG. 7 — *Diagrammatic arrangement (remote control) single effect submerged tube, steam heated*

the dual purposes of allowing a quick start when the unit is switched to ON and when at standby prevents any possible contamination of the condensate through, say, a leaking tube by keeping the sea water side of the tubes at a lower pressure than the condensate side.

FLASH TYPE DISTILLATION PLANT

Flash Principle

The basic principle of flash distillation is that sea water is heated under pressure then released into a chamber where the pressure has an equivalent saturation temperature less than the temperature of the incoming sea water Fig. 8. Since the sea water cannot remain in a super-saturated state a quantity of vapour is flashed off, sufficient to restore thermal equilibrium in the chamber. The released vapour in turn is condensed on a heat exchange surface circulated by the incoming sea water thus recovering the latent heat. It will be seen that as the sea water quantity circulating through the heat exchanger is the same as the quantity of water passing through the flash chamber and assuming no losses the temperature rise over the heat exchanger is the same as the

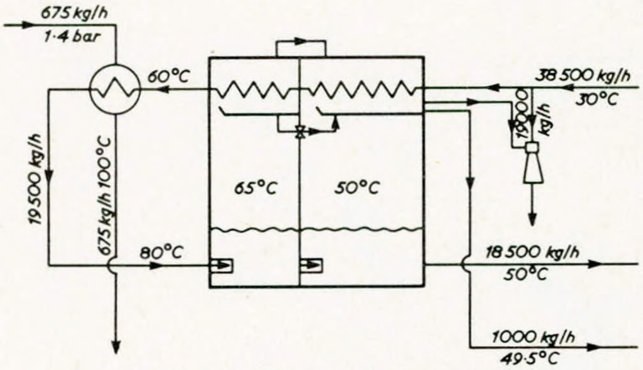

FIG. 8 — *Heat balance, two stage flash*

temperature drop over the flash chamber then the quantity of heat supplied to the external heater must be rejected to waste in the outgoing brine and distillate. The quantity of heat required to produce a given quantity of distillate is a function of the number of flash stages and typical values are shown in the table in Table I. Also shown for comparison is the ratio obtainable from a single effect high vacuum submerged tube plant.

TABLE I — TYPICAL GAIN RATIOS

Type of Plant	Kg distillate/Kg steam
Single-effect submerged tube	0·875 : 1
Two-stage flash	1·5 : 1
Four-stage flash	2·0 : 1
Six-stage flash	3·0 : 1
Twenty-stage flash	6·0 : 1

Two Stage Flash Distillation Plant

A two stage flash distillation plant is shown diagrammatically in Fig. 9. Use can again be made of standard vapour shell modules complete with distilling condenser tube bundles and demisters. Flash chambers are attached in place of the normal vertical tube bundles of the submerged tube plant.

The plant operates on the normal once through flash cycle with part recirculation when necessary to maintain the sea water inlet temperature to the plant at a predetermined level. The sea water supply pump supplies water both to the ejector, which in this instance extracts air and non-condensible gases only in maintaining the necessary operating vacuum, and to the heat exchangers where it passes in series through the second stage, then the first stage recovering the latent heat in condensing the flashed vapour before passing to the external heater to be raised to the top temperature. The heated sea water is then passed in series through the first and second stage flash chambers where a quantity is flashed to vapour in each, the remainder being extracted from the second stage chamber by the brine pump and discharged overboard. In cold sea water conditions a quantity of brine is recirculated under the control of a thermostatically controlled motorized valve to maintain design temperature at the sea water supply pump suction. The distillate produced in stage one cascades to stage two, part of this will in turn flash to vapour to be condensed with the vapour produced in stage two.

The distillate produced in both stages is then extracted by the distilled water pump and discharged to the ship's tanks under the control of the conductivity meter as previously described. The bled or exhausted steam supplying the external heat passes through a thermostatically controlled motorized valve which limits the quantity of steam to that required

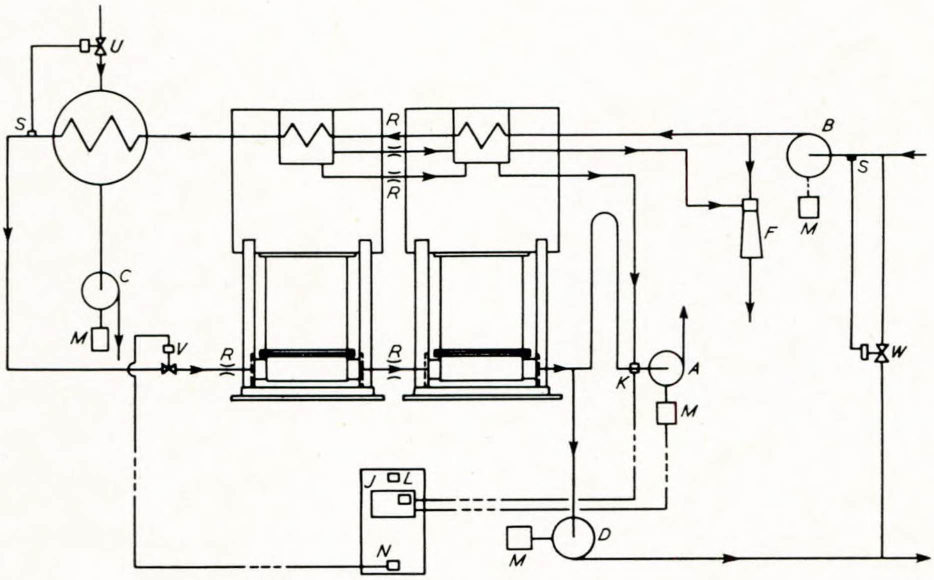

FIG. 9 — *Diagrammatic arrangement, two stage flash distiller*

to maintain the designed top sea water temperature. After condensing in the external heater the condensate is extracted by the condensate pump and discharged to the ships system. The sea water circulating quantity and consequently the distillate output are regulated by a local or remote manually controlled motorized valve. The vacuum differential between stages is maintained by an orifice in the air, distillate and brine interstage connecting pipes.

It will be appreciated that while a two stage plant has been described the flow cycle is equally valid for a greater number of flash stages.

Flash Chamber/Vapour Shell: in the introducion to the previous section it was stated that standard rubber lined vapour shell modules can be used to form a flash distillation plant. While this undoubtedly provides the best solution from the corrosion prevention viewpoint, it does impose some penalty in space required. In a two stage plant the small additional space can probably be tolerated but for greater numbers of stages the necessary space would probably not be available. In this case the solution lies with a custom designed fabricated structure containing the requisite number of stages and protected internally from corrosion by the application of a protective paint which must then be maintained as necessary. Whichever solution is adopted care must be taken in the design of the flash chamber to ensure satisfactory passage of the sea water through the chamber to ensure that every particle of sea water is allowed to reach thermal equilibrium. The static water level in the flash chamber is a delicate balance. If the level is too high the hydraulic depth can prevent flashing to design saturation temperature and should this occur in the final stage can reduce the plant output. If the level is too low vapour slippage can occur between stages particularly under low load operation and plant instability will result.

Remote Control: the starting sequence of flash distillers being more complex, more thought is required for remote operation. Nevertheless, this can be achieved by the addition of a thermostat and intermittent signal transmitter to control the sea water circulation valve and two level switches on the first stage flash chamber, Fig. 10. The external heater cannot

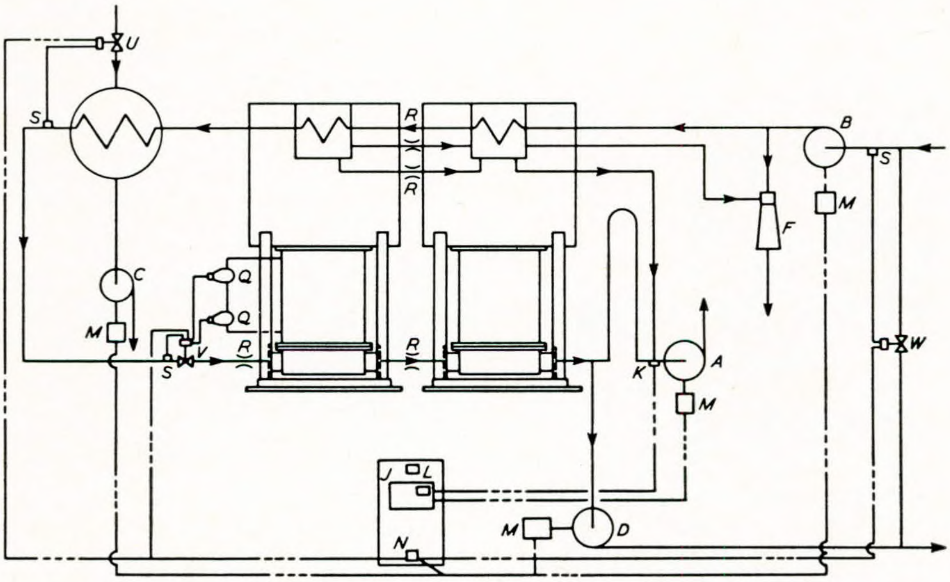

FIG. 10 — *Diagrammatic arrangement (remote control), two stage flash distiller*

transfer the large quantity of heat required to achieve design top temperature with the full sea water circulation quantity until flashing and heat recovery are established. It is necessary therefore during the starting sequence to control the quantity of sea water circulating in relation to the top sea water temperature. To this end the circulation control valve opens in a series of steps under the control of the intermittent signal transmitter and the overriding control of the starting level switch and the thermostat. Once flashing and consequently heat recovery are established the control valve opens fully and control of the sea water circulation is by the inlet orifice under the overriding control of the running level switch operating through the circulation control valve. The heating steam and brine recirculating motorized valves remain unchanged.

VAPOUR COMPRESSION TYPE DISTILLATION PLANT

The vapour compression distiller has attracted much attention over the years due to its high potential gain ratio. In absolute terms there is no theoretical limit to the gain ratio but this woud require an infinitely large heat exchange surface. Allowing a practical temperature difference between the condensing vapour and evaporating liquid imposes a theoretical limitation on gain ratio of some 30:1. This ratio is further eroded by radiation, gland leakage and other losses to a practical figure of 8:1, this should be compared with the ratios given for flash distillation plant.

Principle of Operation

The vapour generated in the distiller shell at atmospheric pressure is passed to the suction of a mechanical compressor which does work on the vapour in raising its pressure and temperature. The compressed vapour is then passed to the heat input section where it acts as a heating medium to produce more vapour in the distiller shell and so the cycle repeats. In condensing in the heat input section the compressed vapour becomes the distillate output from the plant. The cycle is not inherently self starting: consequently an external source of heat is required to bring the liquid to the boil and provide the initial charge of vapour. To conserve the maximum amount of heat in the plant the produced distillate and waste brine are passed through a contra flow heat exchanger giving up their sensible heat in preheating the incoming sea water feed. A typical heat flow diagram is shown in Fig. 11.

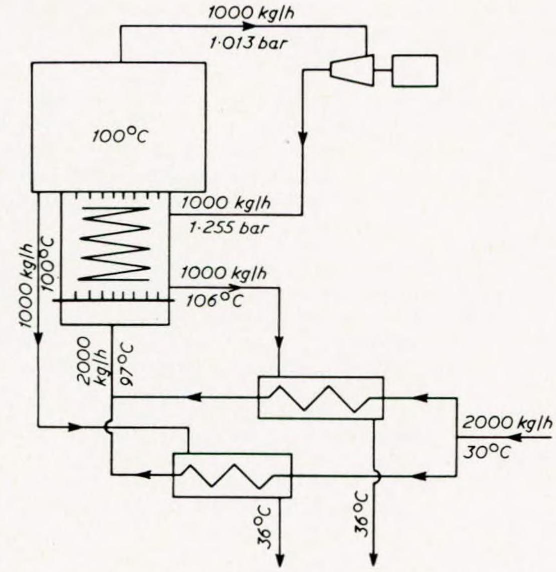

FIG. 11 — *Heat balance, vapour compression distiller*

Vapour Compressor Distiller

Due to the relatively long time scale of the starting sequence it is advisable for plant of this type to be arranged for fully automatic start up and shut down on initiation of a single switch which can be located locally or remotely. A plant so arranged is shown diagrammatically in Fig. 12.

On operation of the starting switch, the sea water supply pump starts, the solenoid operated feed inlet valve opens allowing sea water to pass to the sump through a variable orifice constant flow device and a flow indicator under the overriding control of a level switch, the air pump starts, the solenoid operated air outlet valve opens and the electric immersion heaters are energized to supply the necessary heat for the initial production of vapour.

When the production of vapour has raised the shell pressure to approximately atmospheric the air pump cuts out through the operation of a pressure switch. A further increase

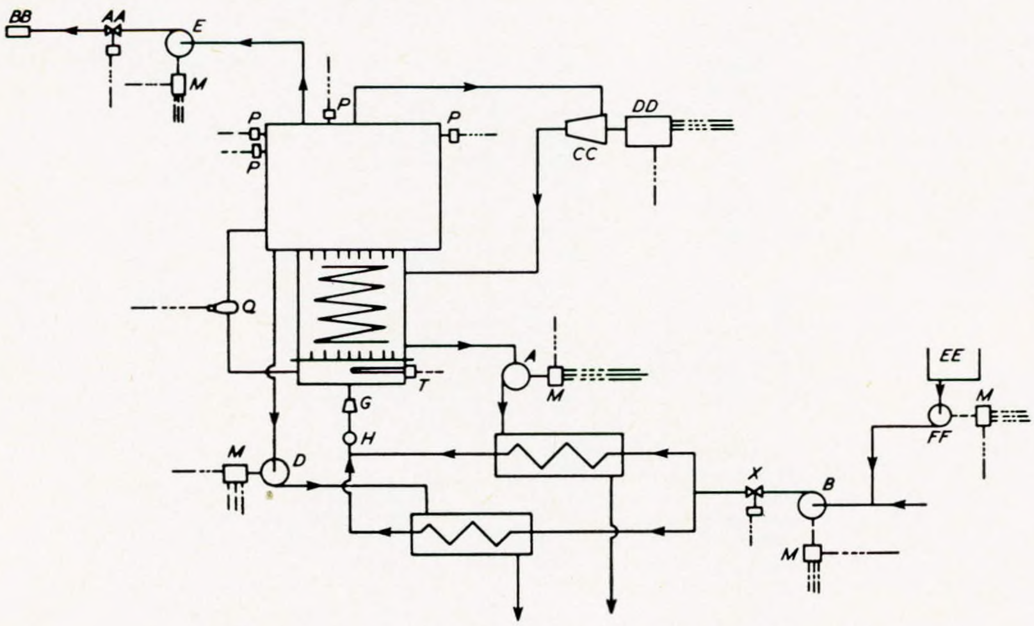

FIG. 12 — *Diagrammatic arrangement (remote control), vapour compression distiller*

in shell pressure causes a second pressure switch to cut out all electric immersion heaters and energize a timer to impose a holding period on the cycle.

At the end of the delay period all electric immersion heaters cut in, the compressor starts and the distillate, brine and continuous feed treatment pumps start. The cycle is thus established and two additional pressure switches cut electric immersion heaters out or in as required to maintain the shell pressure within a narrow predetermined operating pressure band.

Vapour Compressor: There is a choice of two compressor types, high speed centrifugal or slow speed lobe type blower. The centrifugal compressor runs at very high speeds, some higher than 20 000 rev/min, and has a record of blade and particularly bearing failure. There is also a tendency to hunt which is accentuated as the discharge pressure increases due to scale deposition on the distiller tube surface. The slow speed blower has traditionally, on this application, suffered from erosion of the rotor lobes due to carry over of water droplets in the produced vapour. This defect has been greatly reduced since the advent of the demister type vapour separator making the slow speed blower the preferred type.

Feed Preheater This unit requires considerable design expertise. Due to the need to obtain close terminal temperature difference between the incoming feed and the outgoing distilllate and brine the heating surface required is very large relative to the quantities flowing. This requires that either the unit must be multi-flow in the extreme, or velocities lower than necessary for efficient heat transfer must be accepted. In practice a compromise between the two is used, consistent with raising the incoming sea water feed temperature as close as possible to the saturation temperature of the vapour in the distiller shell.

MATERIALS OF CONSTRUCTION

The materials of construction of any piece of machinery must in many instances be a compromise between what is technically desirable and what is commercially acceptable. The sea water distiller is no exception and careful consideration should be given to the choice of material for each and every application.

Vapour Shell

This unit was traditionally manufactured in cast iron which, while it had relatively good anti-corrosion properties in respect of sea water and brine, did have corrosion problems in the vapour space due to non condensable gases. It was also vulnerable to wastage from contact with some of the early feed treatments and cleaning acid.

Subsequently, shells were fabricated in rolled naval brass or cupro nickel and while this gave a technically desirable solution the high cost of these materials proved generally commercially unacceptable and gave impetus to the search for a suitable lining material for the fabricated mild steel shells which are now the accepted standard for this unit.

Protective paints of many types were tested under laboratory conditions and the most promising were selected for further field tests. Despite, however, being applied under controlled conditions which in all probability could not be continuously repeated commercially, none gave satisfactory protection over extended periods. At worst the paint peeled off in sheets, blocking pipework, etc, and at best local deterioration allowed local corrosion of the shell.

By far the most satisfactory lining found to date has been natural ebonite. This is a hard rubber which is applied in 3 mm thick sheets to the steel shell which is shot blasted prior to application of the bonding solution and the sheeting is rolled on to squeeze out any trapped air pockets. The entire shell is then steam heated for the required period to cure the rubber lining before final spark testing. This lining being inert also prevents electrolytic action between the shell material and the non-ferrous tubes and tubeplates and is impervious to feed treatment compounds and cleaning acid in solution strengths much higher than encountered in proprietary cleaning fluids.

Tubes

Tube material in all sea water distiller applications, heat input section, heat recovery section or distilling condenser will almost certainly be aluminium brass. This material gives excellent protection from corrosion by sea water and provided that water velocities are kept below well determined values also gives good protection against erosion. The one proviso to this would be where vessels operate frequently in shallow waters where sand or silt can be entrained in the incoming sea water, the additional cost of cupro nickel tubes can then be justified to prevent erosion of the tube ends.

Tube Plates

Tube plate material used in conjunction with aluminium brass tubes is generally rolled naval brass and the same qualifications and provisos as given for tube material again apply.

Where tube plate area is large, requiring thick and consequently costly plate from the strength aspect, considerable cost saving can be obtained with no loss of corrosion protection by utilizing mild steel tube plates again with a natural ebonite protective coating.

Covers

Heat exchanger covers or waterboxes is one area where the acceptable commercial solution is also arguably the best technical solution. Mild steel plate, again protected internally with natural ebonite provides protection against the three sources of past failure: corrosion due to contact with sea water, erosion due to high water velocities either generally or more usually locally due to reversal of flow causing eddies and electrolytic action between the cover material and the tube and tubeplate material.

DISTILLATE PURITY

Modern sea water dstillers of all types described produce distilled water of very high quality direct from sea water. The purity of the produced water is such that it can be used directly for any shipboard appliction including high pressure boiler make up feed without recourse to double distillation.

The purity of distillate produced is continuously measured by a conductivity meter, commonly referred to as a salinometer. Since this instrument measures all conducting solutes including carbon dioxide, the only correct unit of purity measurement by this method is conductivity units, i.e. reciprocal megohms, also referred to as micromhos. It is, however, usual practice to superimpose a scale on the meter giving a reading in parts per million of either total dissolved solids or sea salt. Under these circumstances it will be appreciated that the reading in p.p.m. is an equivalent one only, the major portion of the conductivity normally being attributable to carbon dioxide particularly in cold sea water conditions where the distillate is undercooled making it more receptive to reabsortion of gases.

To determine the total solids in a distillate it is usual to analyse a sample to determine firstly the total conductivity and secondly the conductivity of the carbon dioxide then, by subtraction, the conductivity of the total solids.

For comparative purposes the following typical distillate analysis was made on a sample of distillate taken from a sea water distiller with a conductivity meter reading of 2 p.p.m. sea salt:

Conductivity	3·35 micromhos
pH Value	6·2
Carbon Dioxide (C.O.₂)	3·5 p.p.m.
Ammonia (NH_3)	Nil
Sodium (Na)	0·1 p.p.m.

This sodium content is equivalent to 0·254 p.p.m. sodium chloride (Na Cl) and is an indication of the total solid content that can be expected in distillate produced by a modern sea water distiller.

SCALE DEPOSITION, FEED TREATMENT AND ACID CLEANING

The ability of sea water distillers to produce their rated output for extended periods can be impaired by the formation of scale on the heat transfer surface of the heat input section. Scale is formed to varying degrees in all types of plant and due allowance is made for this by the inclusion of an adequate fouling factor in calculating the required heat transfer surface.

The predominant scales are calcium carbonate, calcium sulphate and magnesium hydroxide. Calcium sulphate is reasonably soluble in sea water at the temperatures under consideration and can be virtually eliminated by maintaining the brine density at an acceptable level. This function is of course carried out automatically as previously described. Whether calcium carbonate or magnesium hydroxide is deposited on the tubes will depend on the operating temperature. At low temperatures calcium carbonate is relatively insoluble and precipitates whereas magnesium hydroxide is relatively soluble and remains in solution to be discharged in the brine. At higher operating temperatures magnesium hydroxide is precipitated, the changeover temperature being 80°C.

The use of continuous chemical feed treatment cannot prevent the depoition of scale on heat transfer surfaces. It does however lengthen the period between cleaning and the resultant scale is softer, or in the form of a fine sludge which is more readily removed.

Additives in present use are either polyphosphate compounds or synthetic polymers, the former having a temperature limitation in submerged tube plant of some 80°C and in flash plant of some 90°C, the latter has no temperature limitation relevant to existing sea water distillers. Most compounds are dosed at a rate of 1-8 p.p.m. of the incoming sea water feed and it is advisable to use a metering pump for this purpose since in some instances overdosing, particularly of polyphosphate compounds can produce heavy sludges having a similar effect on the heat transfer rates to the scale they are supposed to be minimizing.

The decision whether to use continuous feed treatment or not must be taken with due regard to the commercial considerations, feed treatment chemicals are relatively expensive as are maintenance personnel and cleaning acid. Consequently, the cost of maintenance personnel, cleaning acid and lost water production for a given time to remove deposited scale must be equated to the cost of feed treatment chemicals, maintenance personnel, cleaning acid and lost water production for a lesser period at less frequent intervals to remove accumulated sludge.

In general terms the submerged tube high vacuum plant utilizing diesel engine jacket cooling water as the heating medium and operating at a boiling temperature of some 45°C does not require feed treatment. The steam heated plant however due to its higher tube surface temperature probably does benefit from the use of feed treatment.

In the flash distillation plant all the heat input is added when the sea water is at pressure higher than that where it is possible to generate vapour at the top temperature thus avoiding boiling and consequently lessening scaling of the heat transfer surfaces. Nevertheless, it is advisable at top temperatures in excess of 80°C to use feed treatment. At lower temperatures it is possible to operate without feed treatment.

Due to the arduous operating conditions, boiling at atmospheric pressure, it is essential that feed treatment be used in the vapour compression plant.

Acid cleaning of the heat exchange surfaces of sea water distillers of all types is normally carried out with a 10 per cent solution of hydrochloric acid suitably inhibited. It is important for efficient and effective cleaning that the acid be continuously circulated through the tubes by means of a suitable pump. In the submerged tube plants this is easily accomplished by pumping the acid into the normal feed inlet connexion and allowing it to flow by gravity back to the acid tank from the normal brine outlet connexion. In flash plants hose connexions for acid cleaning are normally fitted at the heat exchanger circulating water inlet and outlet branches.

CONCLUSION

The sea water distiller is a function of the vessels main engine. As such the majority of plants at present in operation are single effect high vacuum submerged tube type utilizing diesel engine jacket cooling water as the heating medium. In the immediate future at least, this trend will continue. Modern plant of this type are reliable, compact, automatic in operation and, when it is realized that sea water containing some 33 000 p.p.m. solids is converted in one step to distilled water containing less than 2 p.p.m. solids, highly efficient. This type of plant will remain unchallenged as the major source of shipboard produced water despite interest in other forms of desalination, as opposed to distillation, be it electrodialysis, freezing or reverse osmosis which have yet to be shown as technically, let alone commercially, viable when operating on sea water.

Of the plant described in this paper the vapour compression type has most potential for future development and interest has been renewed by the advent of North Sea oil and the relevance of the plants to drill rigs and platforms. It remains to be seen however, whether even this market is sufficiently large to justify the necessary expenditure since, despite continual thought and effort being applied to improve the performance of any unit, the driving force behind all development work must be the commercial viability of the product.

ACKNOWLEDGEMENT

The author wishes to thank the Directors of Weir Pumps Limited, Cathcart, Glasgow, for permission to publish this paper.

NOMENCLATURE FOR DIAGRAMS

A	Distillate Pump
B	Sea Water Supply Pump
C	Condensate Pump
D	Brine Pump
E	Air Pump
F	Water Operated Ejector
G	Flow Controller
H	Flow Indicator
I	Strainer
J	Conductivity Indicator
K	Conductivity Probe
L	Alarm Buzzer
M	Pump Motor Starter
N	Rotary Switch
O	Vacuum Switch
P	Pressure Switch
Q	Level Switch
R	Orifice
S	Thermostat
T	Immersion Heater
U	Steam Inlet Valve
V	Circulation Control Valve
W	Brine Mixing Valve
X	Feed Inlet Valve
Y	Vacuum Release Valve
Z	Non-Return Valve
AA	Air Outlet Valve
BB	Silencer
CC	Vapour Compressor
DD	Compressor Motor Starter
EE	Feed Treatment Tank
FF	Metering Pump

Discussion

MR. G. S. MOLE congratulated the author on presenting an interesting and informative paper on a little publicized subject of importance in both the marine and industrial fields.

Sea water distillers had changed greatly since his own seagoing days, when engineers had fought a constant battle with low pressure submerged coil evaporators which would inevitably scale up, and the engineer's main influence had been in prolonging the operating period. The temperature of the heating steam had invariably been excessive, and more often than not the unit had been forced when heating surfaces were clean, accelerating the reformation of scale. To obtain good quality boiler feed it was necessary to double evaporate.

Manufacturers of distillation plants were to be congratulated on the improvements effected to give more reliable units capable of producing high purity distilled water direct from sea water by single effect distillation.

His experience of the modern automatic operated units described had been confined to the single effect submerged tube plant used on steam and diesel ships, and he asked Mr Gilchrist to give an indication of the number of flash and vapour compression units in service and the type of ships in which they had been installed. With the typical gain ratios quoted in the paper and Table I it was most surprising that more of these units were not fitted and some indication of the relative space and cost ratios, inclusive of cost of automation, for the three types would be of interest.

The heat balance diagrams given for each of the types of distillers showed units which operated at one specified level of output. Mr Mole had had experience of submerged tube distillers with automatic control facilities to produce three levels of output, a facility which was a special requirement of the operator. From the author's description of the stable water level requirement in the flash chambers and for temperature regulation and compressor rating in a vapour compression plant, he concluded that variable output facilities could not be provided. Would Mr Gilchrist confirm if that was the case. No indication of minimum or maximum size limitation had been given in the paper or whether any of the units would only be viable at larger outputs. Also how were stable water levels maintained in the flash chambers when ships were rolling in a seaway?

Experience had shown that operational problems with single effect submerged tube plants during a six year period had not been numerous and were generally associated with the peripheral equipment associated with the distiller. Corrosion/erosion occurred on the flow controller seats and bodies, particularly where more noble salt water pipeline materials were used. A change of material was necessary to overcome the problem. Incidences of low flow rate had been reported on fitting new flexible plugs in flow controllers, and adjustments had had to be made by ships' engineers to obtain correct flow rates.

With plants operated from diesel jacket cooling systems, scale formation was very seldom a problem, but on turbine ships the selection of the bled or auxiliary exhaust steam supply was critical in relation to scale forming properties.

He assumed that Mr Gilchrist had not given a heat balance diagram for a steam heated submerged tube distiller because of the wide range of steam conditions which could be experienced in service, but he wondered if he could indicate the maximum steam temperature above which scale formation would be inevitable. Similarly, the maximum allowable distiller outlet temperature would be appreciated.

In his opinion the use of desuperheaters to regulate steam temperature was to be avoided, as experience had shown that the simplest types were difficult to control and susceptible to failure due to sprayers blocking or eroding, and high quality desuperheaters were very expensive. With one class of ship with which he had been associated bled steam had been extracted at approximately 0·6 atmospheres absolute, giving a maximum steam temperature of 95°C.

Under these conditions it was possible to operate the units for four years without using chemical feed treatment and cleaning chemically *in situ* at six month intervals. The system had only been changed to reduce the work load on the ship's staff, and at present constant chemical feed treatment had almost eliminated the requirement for chemical cleaning. He recommended designers and operators to aim for operating temperature below 95°C.

Condensate and distillate pump defects contributed greatly to low output, particularly if the mechanical seal was at fault. Very careful assembly was necessary as the motor and pump shafts were common and seals were not very accessible. Was any consideration given to storage tank situation when sizing the distillate pump as high back-pressures could affect the output from the units? The situation was complicated by the lack of instrumentation originally supplied with the units.

With the advent of UMS operation it was essential that comprehensive instrumentation and records should be maintained because ship's staff were less familiar with operating conditions and diagnosing faults was, hence, more difficult. Would Mr Gilchrist like to explain his philosophies on instrumentation of each of the types of units?

Poor quality distillate had usually been traced to the malfunctioning of the vacuum release valve causing overloading of the demister, or to demisted assembly faults. Even at low temperature operation scale tended to build up on the bottom of the demister, and it was necessary to remove for manual or chemical cleaning; special attention was therefore necessary to ensure correct assembly.

Due to action of the water ejection discharging gases in addition to brine from the unit, erosion damage invariably occurred on the non-return valve. Should the unit be situated at or below sea level, flooding back could occur when the unit was shut down. This could lead to contamination of storage tanks.

Turning to materials: advice would be appreciated on methods which could be used to repair the hard rubber lining in the distiller shell should it become accidentally damaged or detached. Had any experiments taken place to coat the units with glass flake which would be more easily repaired?

Finally: could Mr Gilchrist suggest a solution to producing distilled water over prolonged periods at anchor in areas where fresh and distilled water could not be readily obtained. This was becoming an ever increasing problem in certain areas.

MR. C. TURIN said that as his company had been in the distiller field for over 20 years he had followed the paper with great interest. Mr. Gilchrist had covered quite comprehensively practically all the different fields and alternative methods of distilling sea water, with the exception of the technique of employing the plate heat exchanger principle for evaporating and condensing, as an alternative method to the traditional tube and shell heat exchangers.

The company had used plate heat exchangers for 15 years and were now covering some 25 per cent of the total world market on single stage jacket water heated marine sea water distillers. He was sure that everyone would agree that the plate heat exchanger was now an accepted piece of equipment in the ship's engine room. It had also been used for fresh water and for lubricating oil cooling for quite a number of years.

Referring to the advantages of plate heat exchangers, he said that the heat transfer was considerably higher than with tubular types. Compactness and low weight were important features and, contrary to traditional heat exchangers, the plate heat exchangers gave rather large flexibility as to the heating surface. It was possible to switch round, increase and decrease the heating surfaces according to the actual demand. Also there was flexibility in regard to choice of material.

Choice of materials for heat exchangers was mentioned in the paper. His company's experience had been that even naval brass and cupro nickel were subject to corrosion under adverse conditions, particularly with increased pollution at sea.

In order totally to eliminate the risk of corrosion the company had decided to standardize on supplying the condenser heat exchanger in pure titanium. This was a rather expensive solution, but nevertheless it had been found to pay in the long run. The reason this was only done with the condenser was because it was solely in connexion with reasonably high velocities at sea that erosion and corrosion were experienced, and on the evaporating side they only had the feed which came in at rather low speed.

His company had devoted quite some time and energy to research of the mechanisms behind scale precipitation and the parameters influencing scale deposits, and it had been found that on top of the generally accepted reasons, i.e. the brine feed ratio, an uneven distribution of thermal load would on either side of the heat exchanger surface severely influence the distribution of sea water feed. This was a self-accelerating effect which would rapidly cause precipitation of scale in this particular part of the heat exchanger where the thermal load was high, so one had to make sure that no part of the heat exchanger had been deprived of feed. This could be fuly controlled by the use of plate heat exchangers. For quite some time his company had carried out extensive experiments at sea and had now come to the conclusion that distillers could be run absolutely free from scale.

Another interesting point in this connexion was that the exchange situation had been deliberately altered so that the scale would precipitate and then the situation had been brought back up to normal again and, quite simply, the scale had disappeared.

Referring to Mr Gilchrist's statement (in the CONCLUSION of the paper) that the vapour compression type of distiller had most potential for future development; his company's experience, particularly with the North Sea field during the last couple of years, was that the vapour compression distillers were rapidly being thrown overboard by the dozen because of very severe scale, corrosion, and maintenance problems with the complicated vapour compressors.

As to alternative methods for distillation he thought that reverse osmosis was a very attractive solution.

MR. P. M. LOW M.I.Mar.E. recalled that many of those present had spent interminable watchkeeping hours struggling to produce a few tons of drinkable water from old intractable evaporators. It was, therefore, heartening to have Mr Gilchrist's exposé on the current state of the art and to know that some of the units described were performing well in UMS ships without an engineer's gentle touch at frequent intervals.

Mr Gilchrist had commented in the paper that some owners still specified non-ferrous materials for the vapour shell. This had certainly applied to his company until a quite recent acceptance of some rubber lined mild steel units. The reasoning behind this conservative approach was that any protective coating was only as good as the weakest part, and where breakdown occurred the resulting concentrated corrosion could be catastrophic.

The paper referred to the difficulty, in commercial production, of maintaining the high standards essential for satisfactory coating performance. Mr Gilchrist had certainly found a good solution for his company, but the problem in specification writing for world-wide tendering was to ensure that all equipment put forward to meet the technical specification was of comparable quality. The simple answer to this might appear to be only to buy from the well-known and well-proven manufacturers. Unfortunately, that freedom did not always exist, and the potential corrosion loopholes were therefore plugged in advance by specifying non-ferrous materials.

Coating systems were also vulnerable to mechanical damage and destruction by welding during ship construction, operational maintenance and dockyard repair periods. Such risks were minimized by removing the necessity for dismantling. Chemical feed treatment and the design of units to permit *in situ* acid cleaning were steps in the right direction. Mr Low's company had used feed treatment with polyelectrolytes on both steam and motor ships and the necessity for acid cleaning was very rare.

Brine pumps were always troublesome to keep up to specified performance, and their replacement by water-powered ejectors was a welcome move. It was, of course, expensive in terms of kW consumption, and care must be taken with the choice of the sea water pump to ensure that the maintenance load was not simply transferred from a small brine pump to a large high pressure one.

The use of fresh water on board ship had increased markedly in recent years through improved accommodation facilities, and the use of fresh water for sanitary purposes instead of installing a separate sea water system. The increased cost of fuel and, consequently, the increased cost of water produced on board, made it timely to reconsider this situation in terms of economizing in the use of fresh water and or improving the efficiency of its production. His company's experience, several years ago, with flash evaporators on board ship had not been encouraging, and one was left looking wistfully at the economy of the vapour compression plant.

The immediate objections to the vapour compression distillation plant were, of course, the additional mechanical complexity and the fact that the heating source must be at a temperature higher than the low grade waste heat currently employed on both motor and steam ships. Heating surface temperatures were back in the range where scale formation would be more difficult to combat with feed treatment, and the unloved brine pump had returned.

Could Mr Gilchrist comment on the practical possibilities of a vapour compression plant working below atmospheric pressure to avoid some of these objections? He also asked Mr Gilchrist's opinion on the size and output at which a vapour compression unit might become attractive in comparison with a submerged tube plant.

MR J. M. CRUIKSHANK, F.I.Mar.E., said that the author had set out in the paper the outlines of three main types of simple distillers, the first two being those most commonly installed in deep sea ships but, as everyone knew, the seemingly simple operation of these units could create havoc when they simply just did not produce water. It was a fairly well established fact that in any ship — particularly those with main and/or auxiliary steam plant — with distillers operating satisfactorily other problems appeared manageable. If a water shortage was superimposed, then molehills became mountains.

Naturally, the author had dealt primarily with the equipment between the inlet and outlet flanges, but it was essential that whatever the type a great deal of attention should be paid in the early design stages of any installation, to the system into which the distillers were being integrated if operational problems were to be minimized. In fitting a package unit into a total system this important facet was too often submerged with details left to the tender mercies of the shipbuilder without firm guidance from the manufacturer. The inevitable result was that the equipment and manufacturer got all the "brickbats" when problems arose. These problems were frequently compounded when, with two plants installed, it was sometimes necessary — often under emergency water shortage conditions — to operate both plants simultaneously. A point usually missed was that even a 75 tonnes/day plant could only produce 3 tonnes/h maximum, and two units operating with inadequate plumbing often produced a total output less than that of the capacity of one unit.

The main point here was that it was essential for the supplier to take a specific interest in the overall conditions under which his equipment was to operate and not solely lay down pressure, temperature and flow rate conditions at inlet/outlet flanges. Some of the points requiring consideration were:

a) sizing and physical run of steam piping — to cope with the number of units installed operating simultaneously;
b) position of desuperheating sprays in steam lines supplying heating steam, relative to the distillers — a minimum distance of 5 metres and separate controls for each unit was necessary;
c) size of distillate pump, output head in relation to storage tank dispositions together with any downstream fitting resistances such as a demin plant — keeping common point of multi unit discharges apart as far as possible;
d) position and size of brine ejector outlet piping relative to the ballast/loaded draught heads — separate overboards for each unit.

He asked the author to comment on the policy that he considered should be adopted here.

The introduction of a unit designed to operate specifically at optimum output was not really grasped initially by sea staff (maybe not by shore staff either) who still tried to operate as before, i.e. to continually try to match output to consumption. Every seagoing watchkeeper had his own "secret" position for steam and drain valves which were regularly reset at the start of each watch. Once the fact had been grasped that the units ran better with everything full open and not continually altered, overall outputs had improved. The development and design of control systems to achieve this had been a big step although problems were still being experienced daily with reliability of the feed flow indicators.

Mr Cruikshank did not see the need to over-automate the plants and instal remote control with automatic start-up on the simplified units generally being installed. Why complicate the plant?

Scaling was still the biggest problem and could occur in diesel ships just as easily as in steamers despite the author's statement at the end of the paper. Again this could be the result of trying to operate the plant at partial loads and/or with unsuitable piping arrangements. Table II, showing operating performance taken from steam and diesel ships with different types (including a two stage flash unit) and manufacturers was interesting:

overall layouts had arisen with water hammer in the vertical tube heat exchangers resulting in necking and flattening of the tubes near the tube plate.

The main fault would appear to lie in the position of the desuperheater spray, relative to the control sensor and the length of straight connecting piping to the stack, together with a too tightly designed coil drain system. Other operating problems centered around the frequent choking up of the inlet feed filter and a series of failures of the drains pump seals. He thought there was a universal cry for help here. An addition found necessary to assist initial setting up and control had been the fitting of a gauge glass to the heating stack steam inlet and outlet branches to check the operating water level. Once this was set downstream with systems then there was no problem.

He noticed that in all the diagrams shown the feed line was indicated as being from a separate supply, usually the main evaporating salt water supply pump. Could the author advise him why the service department at commissioning trials had promptly altered this supply to a tap-off from the ejector booster pump discharge, which was drawing from the distilling condenser cooling water outlet, i.e. had a temperature a few degrees higher than the direct sea feed. The view seemed to be that the higher feed temperature would assist production. This was strange, especially for a plant that by design should cope with sea water inlet conditions ranging from 0°C to 35°C.

TABLE II — EVAPORATORS

a) No of Units	1 Each		2 Off		2 Off		1 Off		1 Off		1 Off	
Type:	Flash: 2-Stage Sub: 1-Stage		Sub. Tube (Steam)		Sub. Tube (Steam)		Sub. Tube (Hot Water)		Sub. Tube (Hot Water)		Sub. Tube (Hot Water)	
Capacity Tonnes/Day	Flash: 76 Sub: 35		45		45		35		30		36	
Age of Ship: Years	6		5		3		4		8		3	
b) Production Tonnes/Day	73		65		45		22		29		30	
c) Cost of Dosage/Tonne output Each Unit (£)	Flash: 0·03 Sub: 0·032		0·035		0·035		0·03		0·035		0·03	
d) Total consumption (all purposes) Tonnes/Day	44		30		18		19		13		12	
e) Periods between Cleaning (Months)	Flash: 3 Sub: 4		2		4½		3		4½		5	
f) *Costs — (Sterling)*	73/74	74/75	73/74	74/75	73/74	74/75	73/74	74/75	73/74	74/75	73/74	74/75
Maintenance (Including Spares)	1611·00	1818·00	1714·00	661·00	624·00	185·00	173·00	504·00	1186·00	467·00	382·00	428·00
Cleaning Acid Tonne/Output	0·014	0·014	0·012	0·012	0·0068	0·0068	0·016	0·016	0·0074	0·0074	0·007	0·007
Maintenance and Acid Tonne/Output	0·077	0·085	0·087	0·04	0·046	0·019	0·039	0·066	0·124	0·053	0·044	0·048

The first three ships were VLCC and the others diesel driven, and it would appear that there was very little cost difference in production treatment. The main point was that it was found necessary to treat the hot water units as well as steam operated units.

The period between cleaning on the second ship was now being extended although ship No. 1 appeared to be using too much cleaning acid.

Costs had been checked from two years to determine whether these costs were cyclic, as with most ships on a two year D/D interval. It had been found that in the three cases where costs exceeded £700, major repairs/spares had been required for associated pumps.

It would appear, therefore, that "our daily tonne costs about the same as our daily 'pinta'."

A major problem on several steam plants with differing

He endorsed the author's views that the best lining for the vapour shells was natural ebonite, although these too had been known to fail. More care, however, should be paid to the design of the water box inlets and immediate pipework to minimize tube end erosion through water turbulence — with or without entrained sand/silt.

On distillate lines, the use of non-ferrous piping could assist in minimizing replacement costs in service. Mr Cruikshank suspected that the pH value of 6·2, as quoted, was frequently exceeded and often nearer 5. He had seen a pH of under 4·0 registered with main engines on stand-by. He asked if the author recommended the installation of a mixed bed de-ionizer between the distiller pumps and storage tank to stop corrosion.

The installation of multi-stage flash units was not so common. It was normal on steam ships to instal 2 × 100 per cent units, and more often 1 × 100 per cent on diesel. Despite the increasing use of fresh water for sanitary systems the current single stage units appeared to cope satisfactorily. He asked the author to define where the crossover point occurred in respect of single/multi-stage units.

The author mentioned that the vapour compression unit had the most potential for future use. As the present hot water or steam heated plants utilized heat that would otherwise be transmitted overboard, where did the economics favour the vapour compression units? With higher diesel powers being installed, the ability to generate more electrical power from waste heat was present, but then there was also an increase in the total heat available in cooling water. He asked in what role the author saw this type of unit, and whether he could indicate comparable cost ratios for the various types of plant.

The CHAIRMAN, DR. J. COWLEY, F.I.Mar.E., said he had been interested to see, under the heading "Vapour shell", a reference to spark testing of the natural ebonite lining. He wondered whether this was the same sort of test as was used on fire extinguishers to test the continuity of the internal organic coating. Was it a high frequency high voltage test? Had the author's company taken any special precautions and could he advise on test procedures and conditions in this case, because this test could damage the lining if it were not applied properly. Was this a self-imposed requirement or was it at the request of their customers? He also asked whether the author had considered the use of an alternative test in which the shell is filled with a conducting fluid and an insulated electrode introduced. If a 'megger' insulation test were then applied between the electrode and the metal body of the shell, an infinite resistance should be obtained for a continuous internal coating. In view of the inherent simplicity of the "insulation" test perhaps the author would comment on the relative merits of the two test methods.

As everything seemed to centre on the corrosion problem he wondered if the author had considered using fibreglass for the shells of the units.

MR H. WOODS, M.I.Mar.E., said that to produce water an evaporator must be supplied with various services. These included a heating medium, cooling medium, electric power, maintenance, treatment and surveillance.

If one initially took as an example a single effect submerged coil steam heated evaporator, some of these services could be costed, and for all the examples it would be assumed that the evaporator in question was producing one tonne of water per hour.

Taking design figures, a boiler of 89 per cent efficiency producing steam at 62 bar 515°C would produce one tonne of steam for every 0·073 tonnes of fuel oil supplied. Fuel oil cost £42·00/tonne, so from this one found the cost of steam at the boiler stop was £3·05/tonne. For use in an evaporator one needed to reduce the state of the steam to 1 bar absolute saturated. After desuperheating and reducing, without any heat loss one ended up with 1·3 tonnes of steam, so each tonne would cost £2·35. This would be about the figure for producing that type of steam direct with a similar efficiency boiler.

From Mr Gilchrist's figures, one tonne of steam would produce 0·875 tonnes of water, so using desuperheated reduced boiler steam the heating cost for one tonne of distillate was £2·69 (Table III).

Next were power costs. A condensing turbo-alternator running at normal ship load would use 5·0 kg steam at boiler pressure and temperature per kWh, so the cost of a kWh was £0·0152.

The electric power required to run the evaporator for the provision of cooling water, distillate extraction, brine and air extraction, etc., would be in the order of 40 kW to produce one tonne of water per hour, the cost being £0·61.

The next cost was chemical treatment. This, according to chemical suppliers, worked out at £0·04 per tonne of water produced.

Cost of maintenance of an evaporator was considerable. For a ship having two evaporators the cost incurred for refit, voyage repairs, survey fees, etc., would amount to £2700 per annum, and spare gear would also amount to £2700 per annum. assuming the amount of water that had to be produced was 45 tonnes/day for 360 days per year the resultant cost was £0·33/tonne of water.

The cost of surveillance and maintenance by ship's personnel had not been estimated. In his opinion the correct use of treatment chemicals had reduced this figure to a negligible amount.

Nevertheless, the total of the figures arrived at gave £3·67 for the production of one tonne of water. This struck him as being high enough, but there was more. He had pointed out earlier that design figures had been used. It had been found that auxiliary machinery manufacturers were often optimistic about the performance of their machinery, especially turbine and pump manufacturers about the consumption of steam and power. It had been found on sea trials that for various turbines a steam consumption of 10 to 15 per cent in excess of the design was needed to give the rated output. Regrettably he had been unable to find records of measurement of steam consumption of an evaporator while a ship had been undergoing sea trials, but he would be surprised, with all respect to Mr Gilchrist, if evaporator manufacturers were any holier than any other auxiliary machinery manufacturers.

On top of this, machinery and plant could deteriorate in performance for various reasons and efficiency then suffered. General wear and tear, damaged turbine blades, a bit of boiler treatment on nozzles, scaled and dirty heat exchangers, worn pumps recirculating internally and steam and other leaks occurred. All this had an effect on the cost of water production.

If it was assumed that the main boiler, for some reason, was operating at 95 per cent of its design efficiency, there was

TABLE III — FUEL COST £42·00/TONNE

					Cost	Cost including inefficiencies
Heat cost	Boiler steam cost	Equiv. 1 Bar sat. steam cost		Evap. gain ratio	£2·69	£3·32
	£3·05	£2·35		0·875		
Power cost	Boiler steam cost	T/A spec. cons kg/kWh	kWh cost	Power requirement kW	£0·61	£0·85
	£3·05	5·0	£0·0152	40		
	Chemicals cost				£0·04	£0·04
	Maintenance: £5400 for 360 days p.a. at 45 tonnes/day				£0·33	£0·33
					£3·67	£4·54

a 5 per cent heat loss, and the turbo alternator was running at 90 per cent of its design efficiency, as were various water pumps,and the evaporator itself was capable of 90 per cent of its gain ratio; because these efficiencies or inefficiencies were compounded by each other one got a figure of £4·54/tonne of water produced. If one added a little operator inefficiency the figure climbed higher.

This was not the whole story, of course. There were methods of reducing the cost of water production. Motor ships used jacket water for heat, and the cost of the water produced, when the main engine was running, was reduced to power cost, chemical treatment, maintenance and spare gear. Going back to design figures again for comparisons, and using marine diesel oil for the production of power a tonne of water wouold cost £1·01 (Table IV). If power were produced by a turbo alternator run on exhaust gas boiler steam this might be considered "free", bringing the water cost down to £0·37/tonne, but he did not think power produced in this way was altogether "free'.

TABLE IV — MDO Cost £63·00/tonne

D/A spec. cons gr/kWh	kWh cost	Power Requirement kW	Cost
250	£0·016	40	£0·64
	Chemicals		£0·04
	Maintenance		£0·33
			£1·01

A number of methods to reduce water production cost were open to steam ships. Use of bled steam was the first means. If one assumed that the value of steam fell from £3·05 at the boiler stop to no value when it had reached the main condenser one could gauge the cost of steam by using the replacement factor of steam to the main engine at the bleed point. An IP extraction at 3·8 bar absolute would have a replacement factor of 0·47, so the steam would cost £1·44/tonne and an LP extraction at 1·16 bar absolute would have a replacement factor of 0·29, so this steam would cost £0·89/tonne. Using these figures the cost of a tonne of water would be £2·63 and £2·00 respectively, assuming the heating steam cost was the only change (Table V). It must be stressed that the given costs of steam were only the stated values if the steam came out of the bleed points of the main engine. If it came from any other source, via auxiliary turbines which were less efficient than the main engine or through ranges being "made up" from higher pressure ranges, or by other means, the steam would be more expensive.

TABLE V — Boiler steam cost £3·05/tonne

	I.P.	L.P.	Condensate Cooled (Heat cost 14 per cent of L.P. Bled Value)	2-Stage Flash (L.P. Bled)
Replacement Factor	0·47	0·29		0·29
Bled Steam Cost	£1·44	£0·89		£0·89
Evap. Gain Ratio	0·875	0·875		1·5
*Heat Cost	£1·65	£1·02	£0·14	£0·59
*Power Requirement kW	40	40	20	25
*Power Cost	£0·61	£0·61	£0·30	£0·38
*Maintenance	£0·33	£0·33	£0·33	£0·33
*Chemicals	£0·04	£0·04	£0·04	
Total Cost per tonne	£2·63	£2·00	£0·81	£1·30

Another, or an additional, method of reducing the cost of water production was to use the main system condensate to act as the cooling medium. The bled steam was then used, via the evaporator, to heat the feed. The heating costs, taking the plant as a whole, were reduced to a minimum and the cooling water pump power replaced by a small amount of extra power needed by the main condenser extraction pumps to pass condensate through the distiller.

About 86 per cent of the supplied steam heat went into the feed, so only 14 per cent of the supplied heat had to be paid for. Allowing a total power requirement of 20 kW and using L.P. bled steam, the cost of producing a tonne of water could be as low as £0·81, again assuming all auxiliaries were operating to design.

Turning to the flash evaporator which, with its higher gain ratio, appeared to offer certain advantages, one could do similar calculations. Using the same LP bled steam as before and supplying 25 kW for pumps, remembering a large brine pump was used in this type of plant but no chemical treatment used, the cost of producing 1 tonne of water was £1·30 for a two stage unit. This did not compare too well with a single stage condensate cooled evaporator and, in fact, a multi-stage unit with a gain ratio of 8·9 would have to be used to compete unless the brine were used as a main plant condensate heating medium (Table VI).

TABLE VI

Flash Evaporator — Fixed Costs:		
Maintenance		£0·33
Power		£0·38
	Total	£0·71
Single stage condensate cooled evaporator: Water cost/tonne		£0·81

Flash evaporator — heat cost to compete
= £0·81 − £0·71 = £0·10/tonne water

Using LP Bled at £0·89/tonne steam

Gain ratio of flash evaporator must be:

$$\frac{0{\cdot}89}{0{\cdot}10} = 8{\cdot}9$$

It would seem that where an evaporator of the single stage submerged coil condensate cooled type was designed into a steam plant its production efficiency would be hard to equal. Did this in fact render efforts in the flash and, indeed, vapour compression evaporator field hard to justify?

While doing the above calculations Mr Woods had become a little worried about the gain ratios given in the paper. A tonne of water produced was a well defined item, but the tonne of steam supplied was barely defined as it is, in fact, a measure of heat to be supplied. To make the left hand part of Fig. 8 balance, the steam supplied must be about 75°C superheat at 1·4 bar absolute to have the drains at 100°C. Were these in fact the limits of the standard evaporator supply steam?

MR. J. B. HILL, F.I.Mar.E., in a contribution read for him by Mr H. Donker, said that at a time when shipowners were endeavouring by all means possible to contain repair and maintenance costs it was appropriate that the makers of fresh water distillation plant should present a paper which outlined current design philosophy, and indicated the direction in which efforts were being made to ensure reliability and obtain maximum plant efficiency.

Present designs were the result of a continuous effort, over the last 20 years, to apply basic scientific principles to the production of distilled water aboard ship and were in sharp contrast to the situation prevailing on earlier vessels.

Prior to the second World War, turbine vessels had been fitted with large, simple, submerged coil evaporators using bled steam. Often a stand-by evaporator was installed and a fresh water distiller added. Production of distilled water was usually hampered by rapid scale formation on the copper steam coils and it was not uncommon for ships on certain routes to reduce the work involved in hand scaling coils by producing distilled water for feed purposes from fresh water.

Motorships (and steamers with scotch boilers) had, until a few years ago, no demand for distilled water, and as recently as in the 1950's were being fitted with small shell and coil evaporators. These were seldom used and had been known to be opened up only when Lloyd's survey requirements so demanded. Upwards of 200/300 tonnes of fresh water was carried for domestic and boiler feed purposes, and water tanks were topped up at every port of call.

About 25 years ago attention had been focused on the gains in space and deadweight capacity which could be achieved if the quantity of fresh water carried could be reduced to a minimum and the evaporation of salt water relied upon to maintain supplies. As a result of this development, ships had been (and were) expected to be able to leave port with no more than 50/60 tonnes of fresh water on board, thus putting a considerable responsibility on the manufacturers of distillation plant to provide equipment which was almost 100 per cent reliable.

It was not current practice to install any stand-by distillation facilities, and the cost to shipowners of fresh water generator failure could be considerable. Loss of fresh water generating capacity could at best result in fresh water having to be rationed or, as happened from time to time, ships having to be diverted for fresh water at a cost of some thousands of pounds if loss of hire was taken into consideration.

Today, shipowners required a basically simple plant which could consistently maintain an output approaching the designed figure and was stable in operation regardless of slight variations in heat input, sea water temperature, draught, etc.

One had the impression that there was a tendency for manufacturers to quote optimum output figures for their equipment rather than average production over extended periods. It was not unusual for average output to be about 80 per cent of design and the prudent shipowners often felt it necessary to specify a larger distillation plant than was theoretically necessary. This was an area in which closer co-operation between designer and operator would be beneficial.

The reasons why output could not always be achieved or maintained were not always obvious, and it was not unknown for service engineers to have difficulty in pinpointing the faults which restricted evaporator performance.

Usually low output could eventually be traced to one or other of the following causes:

1) incorrect installation of pipework affecting flow rates;
2) air leakage causing loss of vacuum;
3) inefficient ejector operation;
4) fouling of heating surfaces and demisters.

As far as 1) was concerned, there was a need for maximum liaison between shipbuilder and manufacturer to ensure that installation was correct and that designed operating conditions were achieved.

Clearly, in some contemporary fresh water generator designs, rated output was almost too dependent upon maintaining a delicate balance between the various operating parameters. As there was usually ample waste heat available in the form of cooling water, or steam generated by exhaust gas, on present day motor vessels, one wondered if it was not preferable to accept some loss of efficiency for simplicity in operation.

A problem facing shipowners from time to time was the production of fresh water, when ships were at anchor awaiting berthing facilities. In some cases pollution made the generation of fresh water impractical, but there were instances on board motor ships when the ability to produce fresh water, albeit suitable only for auxiliary boiler feed purposes, would avoid ships having to enter port solely for fresh water, or possibly the need to weigh anchor and steam around to produce water.

He asked if the author would give his views on the fitting of steam coils to hot water evaporators. Alternatively, would it be preferable to install a fairly large steam heater in the main engine cooling water system, so that the hot water heated evaporator could be used in the normal manner? A third possibility could be to fit a small vapour compression unit to work in conjunction with the main hot water evaporator, in estuarial waters.

The objection to the introduction of steam into submerged tube evaporators was undoubtedly because of the risk of accelerated scale formation, but this could possibly be offset by increasing chemical dosage. The author had discussed the subject of chemical injection at some length and made useful recommendations, but one was rather surprised that treatment was considered unnecessary in hot water evaporators. Possibly, if designed operating conditions could be maintained, cleanliness of heat transfer surfaces would remain satisfactory. Unfortunately, many evaporators were equipped with little more than a vacuum gauge; consequently it was difficult to be sure that correct balance was being maintained.

The advances made in the lining of evaporator shells were of considerable interest in view of the very severe localized attacks suffered by mild steel shells when coatings broke down. Repairs to damaged shells were not easy in evaporators of modular construction and replacement of sections of the vapour shell sometimes impossible without dismantling the unit entirely. The use of hard rubber would appear to be an advance on paint coatings, providing integrity of the bonding could be ensured. In the event of failure, was it possible to renew the rubber coating *in situ*, or would the shell have to be returned to the manufacturers? It would also be of interest to learn if the use of stainless steel cladding had been considered, as its use for cooler water box doors was gaining ground.

Having dwelt at some length on the hot water design of evaporator, he said one should not dismiss the potential application of the flash and vapour compression plants to steamships. It was understood that the flash evaporator was relatively stable and thus readily lent itself to unattended operation. On the other hand, if the prime object behind the development of the flash and vapour compression types was improved efficiency at the expense of added complication and maintenance, there might be a case for retaining the simpler forms in present economic circumstances.

Summing up, he said that today's requirements for cargo ships, bulk carriers, etc., were for simple plant, easy to maintain and capable of steady output, rather than maximum efficiency. It might be added that ease of maintenance included the provision of adequate access for inspection and repair, together with well designed cover joints, pipe couplings and other parts which had to be disturbed at refits and be airtight when reconnected.

MR. H. DONKER, F.I.Mar.E., said that perhaps the biggest single development which had made the modern evaporator so reliable and consistent in its output was the replacement of brine and vacuum pumps with high pressure sea water ejectors. Now this stage of reliability had been reached, concentration on design should be channelled to ease of maintenance.

One predictable aspect of evaporator running was that even when operating under optimum conditions, chemical cleaning would be required after a certain period. Chemical cleaning *in situ* was dangerous in that risk of contamination of domestic or feed tanks was always possible.

Easily removable heating elements and condenser cooling elements would have some advantages, such as:

a) a spare was always at hand in case of failure of an element;
b) a quick replacement of a scaled element could take place, thus reducing out of operation time;
c) risk of chemical contamination was eliminated;
d) repair and inspection of shell internals were made easier with the element removed.

Coating of evaporator internals was a problem. The impregnated rubber type coating could be the answer, but attention to shell mountings and connexions should be made to ensure that no welded repairs were necessary in the life of the evaporator.

The necessity for remote starting of an evaporator was debateable. Certainly remote stopping would be useful. it was suggested that local starting did help ensure that all isolating and system valves were checked locally, and worked while setting up.

Simplicity and robustness of parts, including ancillary equipment, must still be the main requirements for most marine machinery, especially in the days of reduced manpower.

With regard to the amount of water required to produce, in many trades with quick in port turnrounds a small tank capacity combined with being unable to produce water in port could be justified. In some trades this could not be, for example, the chemical trade. Copious amounts of boiler make-up water were required in port when tanks and lines/machinery, etc., were steamed out for cleaning with total loss of condensate. Use of fresh water for make-up could quickly scale the boilers, and an alternative heating element inthe evaporators, such as a steam coil in port, would certainly be useful even for just producing distilled water for boiler feed, either from harbour water or fresh water.

MR. A. HADDOW thought it might be useful if he tried in about five minutes to describe the basic applications, the processing and the hazards involved in rubber lining.

Protective linings were classified into four categories: anti-corrosive paints, applied by brush or spray: these were normally built up in layers of about 0·05 mm: thermosetting and thermoplastic materials, applied in liquid or semi-liquid form: these could be built up from 0·5 mm to 1·5 mm: polymeric materials, applied in sheet form, with individual layer thickness of 1·5 mm to 6 mm: rubber could be built up to an inch thick (25 mm) if one wished.

Many metals nowadays could withstand any given condition, but there was a cost factor which was very important, so that by applying a rubber lining an economically viable job could be obtained.

Most polymers could be used for lining. The types used on the distillers were hard natural (ebonite), and soft natural rubber. Ebonite was used in the shell internals and the soft rubber on the flange faces to give an adequate airtight seal. Ebonite was chemically stable so that ageing presented no problems; it had a good combination of physical and chemical properties, was particularly effective where maximum resistance to leaching was required and was resistant to most chemicals, even in hot solutions at high concentrations. Rapid changes in temperature and mechanical shock should be avoided. This was particularly important at the lower end of the temperature scale.

The soft natural rubbers were especially good in concentrated conditions and had very good abrasion resistance properties.

It was also possible to line in neoprene, nitrile and butyl. All these polymers were used as rubber linings. Temperature was the one limitation as far as rubber was concerned. Natural rubber under continuous operating conditions would break down above 100°C. One could get slightly higher temperatures with Neoprene and Butyl, probably up to 110°C, but this was the temperature limitation.

Like all other processes, the most important factor in rubber lining was proper preparation. There was a British Standard laid down which had to be strictly observed. The surfaces must be smooth and free from irregularities, such as roughness, sharp edges, grooves, cracks, hollows, projections, weld spatter, burrs, etc., and they must be free from oil, grease, paint, etc. When metals were received from fabricators it was necessary to have a fairly thorough inspection. If there was a weld crack, no matter how small, air was entrapped when the rubber was applied and when it was cured the heat could blow the rubber right off the metal.

The basic process was to shot blast the metal to be lined to a white bright surface. Immediately thereafter this was sealed by a sealer and adhesive. This was grey in colour. Then two further coats of adhesive (pink in colour) were added. The colour difference visually indicated complete coverage. The rubber sheet was then taken in its uncured form, and panels were cut to suit. Prior to the bonding the rubber surface was softened up with a solvent, and a clean wrapping cloth was immediately applied — this acted as a liner. The cloth wrapper was rolled down in stages between rubber sheet and metal until the complete panel area had been adhered to the metal. The panel was then rolled by hand roller or stitcher to drive out any air which might be trapped between rubber and metal surfaces. Each panel was joined by overlap skived joints. Then the covered surfaces were spark tested, using 20 000 to 30 000 volts, with a probe or a brush.

The rubber industry was basically a cooking industry. One started off with a dough, mixed it, and then cooked it. Fabrications lined with uncured rubber were put in a pressure oven, a large autoclave, which was initially pressurized by air. This was to hold the rubber in position during temperature rise. Steam was then admitted and once the air and steam pressure equalized the air was shut off. The temperature was then raised to approximately 285°F (140°C) and held for two to three hours. Over the next 10 to 12 hours the steam pressure and temperature was gradually reduced, during which time the curing cycle was completed. The rubber had now formed a homogeneous bond to the metal.

There were standards laid down for testing the bond strength but once the rubber had been cured to the metal one could not waste the piece of rubber lined equipment by trying to do a strip test. In some cases a sample piece of metal was rubber lined, processed and cured along with the main unit. The test piece could then be tested for bond strength. When the equipment came out of the autoclave it was thoroughly inspected visually to see if there were any blisters, etc. and if the correct hardness had been established. Thereafter a further high frequency spark test was carried out. Repairs could be made at this stage. Vacuum tests could also be done.

The problem with rubber lining was that nearly every piece of equipment went on for further treatment and the rubber liner had no control over the handling. Various hints were offered on what not to do with rubber lined equipment.

Welding should never take place on a rubber vessel; naked lights should not be used in the vicinity of rubber lining, and heat in excess of recommended temperatures must be avoided because that could accelerate ageing. Once the rubber was cured provided it stayed within its heat range it would last for years, but if one went above that heat cracking and degradation would occur. It should not be submitted to rapid temperature changes, particularly at the low end of the scale. External paint should not be burnt off. Ladders or scaffolding should not be used inside rubber lined equipment without protection. The lining should not be exposed to strong sunlight. In short, any rubber lined equipment must be handled with the utmost care.

Correspondence

MR. E. JENKINSON, M.I.Mar.E., contributed in writing stating that from the paper and the subsequent discussion two main factors had emerged:

a) modern distillation plants now produced water of a very high purity for extended periods when compared with plants of a few years ago;

b) shipowners still had distillation plant problems.

The boilers for a VLCC cost in the region of £750 000, the corresponding distillation plant for 50 tonnes per day about £10 000; since the performance of the distillation plant was essential to the well being of the boiler it might therefore be argued that the approach should be "how can we build in more quality to the distillation plant" not "how can we make it cheaper". The lead for this approach could only come from the ship owner by tighter specification.

The cost figures of distilled water per tonne given during the discussion by a representative of a large tanker owner showed cost evaluation to be essential when choosing one type of plant from another, i.e. multiple effect compared with single effect. This costing approach might be taken a step further, by using historical information from ships to illuminate areas of engineering which needed more built in quality, and would be a useful counterweight to the superficial argument that the cheapest was acceptable. From the heat of the discussion on the shipowner side it would seem as though they should not take too much convincing that 'cheap' distillation plants were not in their long term interests.

MR. A. HEWISON wrote that for a number of years he had sailed with the author's company's distillers and wished to take this opportunity of discussing a few minor details.

With reference to Fig. 2 where mention was made of conductivity meter monitors, where the meter operated in a unique manner he thought that in theory this sounded excellent. However, his experience was that this system did not operate exactly as desired. For instance when the pump had stopped due to excess conductivity, and, when as the conductivity fell the pump cut in. Very shortly after this due to the conditions existing at the meter (probably turbulence) which existed in the pipe at this instance, the pump automatically stopped due to the apparent increase in conductivity.

This phenomena could be overcome in a number of ways, one of which was to by-pass the conductivity meter for a short period, but this then defeated the whole object of an automatic system. He would like to know if the author had come across this particular problem, and if so, how he has solved it.

Also referring to Fig. 2 when the feed strainer became choked — could this not be overcome by fitting a change-over filter in the line thus ensuring that one strainer was always clear?

With regard to the natural ebonite lining this appeared to fail first at the mating surface of the shell and tube nest flanges. Would the author comment upon this which could possibly be due to over loading fastenings of these components — would it be possible to supply standard repair kits with the other spare gear provided to repair this ebonite liner when it was damaged?

In the single effect evaporator the corrosion problems in the shell appeared to have been eliminated, but, this was at the expense, it would seem, of all supporting pipe work. He referred to a particular bend (down stream from K Fig. 2) which wasted very quickly and wondered what materials the author would suggest to eliminate such rapid wastage. As a final point he would confirm that the system operated efficiently if adequate attention were paid to the continuous chemical injection, the heating temperature, and flow rate. However, if the orifice plates flow controllers deviated from their norm then this system no longer functioned efficiently. In order to ascertain which perameters were at fault would it be possible to incorporate basic instrumentation in the unit i.e. vacuum gauge, booster pump pressure gauge, distiller pump pressure gauge and heating temperature. These readings would enable a trend chart to be mapped out thereby ensuring that predetermined efficiency limits were not exceeded. There were a number of distiller manufacturers who incorporated a sight glass in the distiller. Had the author's company any objection to fitting this to their units?

Author's Reply

MR. GILCHRIST was extremely gratified by the interest shown in the paper and by the number and depth of the questions which enabled him to expand some aspects and to discuss some points not originally included.

Mr. Mole had given an excellent description of the trials and tribulations of the traditional sea water distiller now thankfully a thing of the past.

Regarding the number of vapour compression and flash plant and the type of vessel to which they were fitted, he would confine his answers to merchant vessels only. While many vapour compression plants had been fitted on oil rigs, naval vessels and land installations, to date none had been fitted on merchant vessels. The plant was, of course, only relevant to the gas turbine powered vessel and recent increases in fuel costs had effectively halted the development of vessels with this type of propelling machinery. Utilization of flash plant had again been largely land-based. Development of plant of this type came too late to exploit the market for which they were ideally suited, the main line steam turbine powered passenger vessel which was traditionally fitted with triple effect submerged coil plant with an operating pressure of 1 to 1·5 bar in the first effect shell with attendant scaling problems. Nevertheless, there were some twenty installations in merchant vessels the majority being retro-fitted in passenger vessels, notable exceptions being the *Northern Star* and *Queen Elizabeth 2* which had flash plant fitted as original machinery.

The above numbers should be compared with literally thousands of single effect plant in service.

It was difficult to give a relevant cost comparison of the different plant types since flash plant of multiple stage configuration were of much larger output than other types. Table VII, however, gave a comparison for four plants each of 50 cubic metres/day capacity.

TABLE VII

TYPE	COST	VOLUME
Single effect (hot water)	£10 000	12 cubic metres
Singe effect (steam)	£9000	7 cubic metres
Two-stage flash	£27 000	20 cubic metres
Vapour compression	£40 000	22 cubic metres

It was normal practice to operate vapour compression plant at constant rated output to maintain the best possible thermal balance. At reduced output heat losses became disproportionately high, making it impossible to maintain thermal equilibrium. In flash plant it was a simple matter to incorporate variable output. By reducing the quantity of sea water circulating by means of a manual or remotely operated valve the produced distillate was automatically reduced in proportion. Water levels were maintained, regardless of throughput and ships motion, by a system of wash plates and weirs.

Single effect submerged tube plant could operate with a wide range of steam pressures. Ideally all plant would operate with steam at 0·6 bar allowing an operating steam temperature of 95°C. Since the ideal could not readily be achieved he would impose a practical limitation on steam pressure of 1·4 bar and temperature of 110°C. Similarly the circulating water outlet temperature should ideally not exceed 40°C again with a practical limitation of 55°C.

The total discharge head available at the plant outlet from the distillate pump and water operated ejector were always clearly stated. Unfortunately some shipbuilder's equated total head with static head making no allowance for frictional losses due to pipework, bends, valves, etc., this resulted in reduced output from the plant. Where discharge heads greater than standard were required it was a simple matter to accommodate this at the design stage.

Mr. Gilchrist's philosophy on instrumentation was quite straightforward; he believed that instrumentation was necessary for plant commissioning and trouble-shooting. At all other times it was superfluous as in a ship's engine room instrumentation was subjected to mechanical and vibrational damage leading to inevitable inaccuracy. In that condition unnecessary adjustments were often made to the detriment of the plant (as confirmed by a later contributor). When trouble-shooting he always carried the required instrumentation — which he knew to be accurately calibrated — to replace any that might have been fitted. He considered it necessary, however, that the essential services to the plant be continuously monitored to give warning of an alarm condition.

Should the natural ebonite lining be accidentally damaged it was a simple matter to effect a repair. The damaged material was cut back to sound ebonite and the shell material wire brushed. Replace material was cut to the required shape and applied to the shell using an adhesive solution. The patch must be carefully rolled to drive out any entrapped air and finally a cold curing solution was applied.

Laboratory experiments have indicated the possible suitability of glass flake as a shell lining material. A shell so coated was at present undergoing field proving trials.

Much thought had been given to the production of fresh water from plant utilizing diesel engine jacket cooling water as the heating medium when the vessel was at anchor. Three possible solutions were available:

1) Direct application of low pressure steam to the heating element. This was the original solution, basically for emergency use only, which had since become the normal anchor operating condition. It would be preferable to see heating by this method restricted to 24 hours and certainly not more than 48 hours since the heating element was designed initially for hot water heating and could scale rapidly during prolonged operation on a steam supply that must be manually controlled.
2) Injection of medium pressure steam by means of a steam inductor. In this system the steam not only supplied the heat for evaporation but also the motive force to circulate water in a closed loop through the heating element. The system was satisfactory when the heating element was clean and could transfer all the heat in the steam passing the nozzle which, being a critical orifice, passed a constant quantity. Once scale became deposited on the element

however, the total heat in the steam could not be transferred and consequently the temperature in the circuit rose thus more rapidly producing scale which in turn forced the temperature higher and the system became self scale generating. The system was also susceptible to water hammer and vibration.

3) Application of low or medium pressure steam to an external steam heater in the hot water circuit. This could be an extension of the jacket water heater and could be circulated by the main jacket water cooling pump or, if this was very large relative to the quantity required by the sea water distiller, by a separate circulating pump. The supplied steam could be controlled by a thermostatically operated valve and the entire system was then automatic. The system was unfortunately the most expensive in first cost and, due to the inclusion of the circulation pump, also on running cost but was undoubtedly the most satisfactory from the operation viewpoint particularly where extended operation at anchor was envisaged.

Finally, he must correct Mr. Mole on one point. During shut-down, if sea water should gain access to the shell either through the brine or feed systems the storage tanks could not be contaminated. A relief valve fitted on the air suction piping would discharge sea water to bilge at a level much lower than that required to reach the distillate system.

Turning to Mr. Turin's contribution Mr. Gilchrist was, of course, aware of the use of plate type heat exchangers in sea water distillers, not only in the single effect high vacuum plant but also in flash plant and vapour compression plant. Their use in an overall context was, however, relatively minor compared to tubular heat exchangers and in no way altered the flow diagrams or general description of plants.

He was surprised, not to mention sceptical, of Mr. Turin's claim to a scale-free sea water distiller. As the author had already stated, even the use of continuous feed treatment could not completely eliminate the formation of scale and he stood by that statement irrespective of the type of heating surface used.

Having manufactured sea water distillers for over 100 years his company had been in the forefront of research into the formation of scale including papers presented to learned societies, one of which was still regarded as the definitive work on the subject and was quoted by manufacturers of feed treatments in their technical literature. It had been shown that scale formation was proportional to the quantity of scale forming salts in the incoming feed for a given set of conditions. Mr. Turin had stated that plate type heat exchangers had high heat transfer rates giving compact heat exchangers. This implied that smaller surfaces were utilized than in tubular heat exchangers and it followed therefore, that since scale was proportional to feed and consequently output for a given brine density, then the scale deposited on the smaller plate type surface would be proportionately thicker thus requiring more frequent cleaning. This had been the experience of more than one shipowner who had recently replaced plant containing plate type heat exchangers with plant containing tubular heat exchangers.

Regarding materials, aluminium brass tubes were generally accepted as suitable for most conditions with cupro nickel as first choice for more arduous conditions. He accepted that for certain applications, where a plant was operating continuously under adverse conditions the cost of titanium could be justified, but for normal deep sea use with occasional harbour operation it was difficult to justify the high cost of titanium as a standard material unless the high velocities referred to in this contribution were so high that only titanium could ensure a reasonable operating life for the plate type heat exchanger.

A considerable number of vapour compression plants of American origin had been removed from North Sea oil rigs in the past few years, mainly with high speed centrifugal compressors. The author's company had supplied a number of alternative designs to these installations to replace the rejected plant. He accepted that problems still existed with vapour compression plant and this was the reason he contended that the vapour compression plant had most scope for future development. Conversely the single effect and flash plants had reached a stage of development where there was little room for future improvement.

The principle of reverse osmosis had of course been known for many years and the process was used in the pharmaceutical industry where the end product was relatively valuable. The process had also been used to desalinate well water but had yet to be shown technically viable in desalinating sea water. Even for use with well water the process required careful pre-filtering of the feed, and continuous injection of a chemical had been used, though base exchange softening of the feed was now favoured.

The company had carried out research in this field but, since the reverse osmosis plant was considerably more expensive than any sea water distiller and problems existed in desalinating sea water, it was not anticipated that the process would be commercially viable in the near future.

Mr. Low had made out a strong case for an owner specifying non-ferrous shells. In world wide tendering it was necessary to be certain of the quality of the product. The author would obviously prefer that the ship owner should specify the equipment of a well known manufacturer but, since the shipbuilders of certain countries were known to have intense nationalistic tendencies, it was perhaps expedient to specify the expensive solution of non-ferrous shells rather than accept a lining or protective coating less well proven than natural ebonite.

The replacement of the brine pumps by a water operated ejector had been a great step forward in the reliability of the sea water distiller.

Brine was greatly diluted by admixture with the operating water effectively preventing scaling of the overboard discharge piping and valves which was previously a serious problem. In general terms the maintenance load was reduced since scale had been a recurring problem with brine pump seals and had even been known to cause mechanical damage to impellers. The brine pump was withdrawing liquid from a vessel operating under vacuum, and damage to the seal immediately put the pump and plant out of commission. Damage to seals of sea water pumps occurred less frequently and, since leakage from this source had largely a nuisance value in that the effectiveness of the ejector was not impaired, replacement of the seal could be carried out as a matter of convenience rather than necessity.

It was not Mr. Gilchrist's intention to advocate the use of the vapour compression plant on conventionally powered vessels, only on gas turbine powered vessels, nevertheless he had prepared a graph (Fig. 13) showing a viability investigation of the three plant types for which costs had already been given. In preparing this graph the figures given by later contributors for steam, power, maintenance, spares, chemicals etc. had been used, though it would appear that different shipowners put different values on certain of these services.

The operation of a vapour compression plant under vacuum was not really a practical proposition. Under vacuum the specific volume of the vapour being handled increased dramatically with consequent increase in compressor size and power. Additionally a continuous method of air extraction would be required to remove the incoming gases and maintain the necessary vacuum. The total resultant power increase would be sufficient to erode the equivalent make ratio of the plant to the point where it became non-viable.

Mr. Cruikshank had made a very valid point regarding dimensions of pipework suppling services to the plant. Diagrammatic arrangements were produced, clearly indicating the required pipework diameter including any taper pieces. Too often, however, this was ignored and reduced diameter pipework fitted, with unfortunate results. Where two plants were fitted, even where one was intended to be on standby only, then the probability was that both would be run in parallel particularly when water was required quickly during an emergency. To achieve satisfactory operation it was essential that all pipework be adequately sized for simultaneous operation of all installed units. Pipelines from the plants should preferably be run independently but, where it was essential that pipelines be combined, the area of the common pipe should not be less than the sum of the area of the independent pipes.

The points regarding discharge head on the distillate pump and combined ejector had already been answered.

The figures produced in the table were of particular interest in that it was difficult for manufacturers of auxiliary machinery to obtain factual operating figures for differing plant over extended periods of time. The figures for chemical dosage were remarkable for their consistency, one would have at least expected a higher rate for the flash plant due to its higher feeding or circulation rate. This might account for

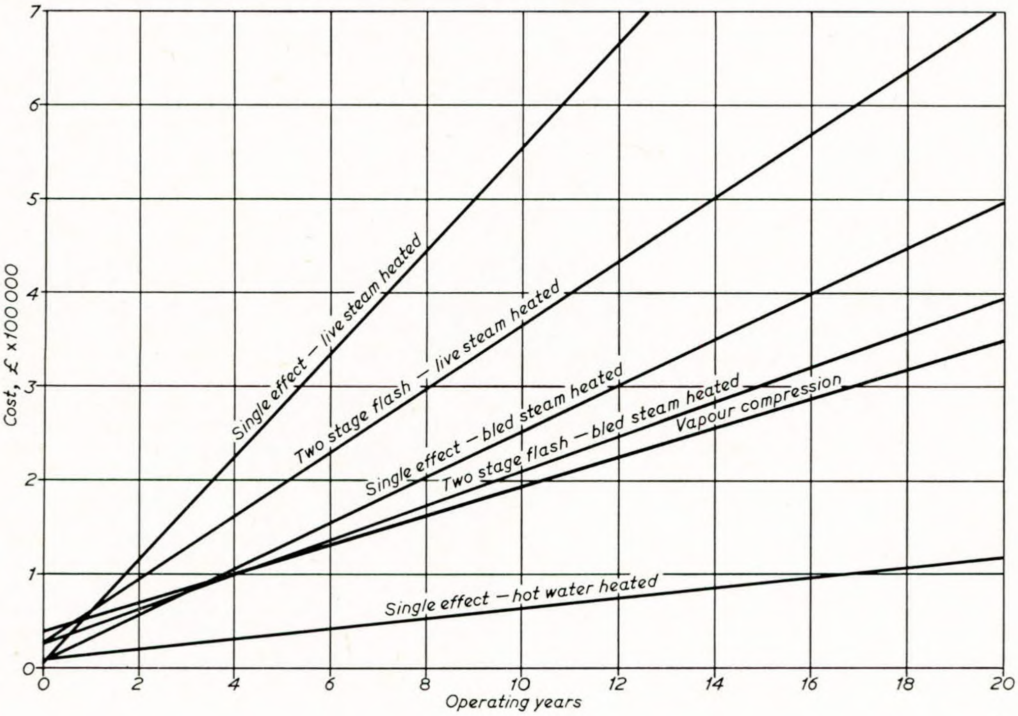

FIG. 13

vessel No. 1 appearing to use too much cleaning acid. Perhaps a higher chemical dosage rate would be beneficial in reducing the cleaning acid quantity, but again, this must basically be an economic decision. It would have been interesting to learn if any of the hot water heated plants had spent any appreciable operating time on emergency or anchor steam conditions.

Water hammer had long been a problem in steam pipes and the fitting and use of adequate drains was essential in its control. Obviously any appliance whose function it was to inject water into a steam line must have careful thought given to its positioning and the author would endorse the criteria given. He could not agree, however, that condensate drain systems were too tightly designed, where problems existed it was due to inaccurate adjustment of the desuperheater. For satisfactory control, steam temperature should be regulated to some 5°C above the saturation temperature, where attempts were made to regulate to the saturation temperature it was not possible to know whether the correct quantity of spray water was being injected, or an excessive quantity thus over-loading the condensate drain system.

Failure of condensate drain pump seals could generally be attributed to two causes. Traditionally the condensate drains were returned to the drain cooler/L.P. heater where the sensible heat in the drains was returned to the feed system and the condensate pump had a positive head to discharge against. In a number of recent installations drains had been returned directly to the main condenser at very high vacuum, resulting in the condensate pump operating in a continuously cavitating condition with consequent damage to the pump internals including the seal. The other cause of failure was operating the plant beyond the point where acid cleaning of the element was required, causing drains at excessive temperatures to pass to the pump.

It was difficult to accept the logic of calling the choking of the feed inlet filter a problem. The filter was fitted to protect the feed indicator and controller — if it was filling with marine debris then it was fulfilling its design function.

With regard to the feed being taken from the ejector booster pump this was not done to conserve heat but to ensure adequate pressure at the inlet to the feed flow controller. Previously the feed had been taken from the general service pump which could be two decks lower than the sea water distiller and, dependent on the services being supplied at any given time, could give insufficient pressure at the inlet to the feed controller. Mr. Gilchrist apologised if his diagrams were misleading but he had had the feed supply shown separately purely for clarity of presentation. All contract diagrams however clearly showed the feed taken from the ejector booster pump discharge.

It was not his intention to suggest that the different plants were alternatives for similar vessels. He had set out under "Types of Plant" the circumstances under which each would be utilized; comparable costs for each type had already been given, together with the Fig. 13 graph, indicating crossover points.

Replying to Dr. Cowley, the author regretted that he had no knowledge of the method of testing coatings used on fire extinguishers.

The test carried out on the sea water distiller lining was a high voltage, high frequency spark test of 20 000 volts. Testing was carried out at the liners factory by personnel experienced in the use of the necessary equipment in accordance with the relevant British Standard Code of Practice. As damage could result from incorrect test procedures it was important to employ a sweeping motion with the electrode which must never be allowed to stop too long in any one position. When the electrode of the high frequency unit was applied to a lined surface having no faults a bluish corona discharge would be seen, there was also an audible indication from a steady buzzing noise. When the electrode passed a fault the corona discharge faded and a bright spark was observed arcing directly to the point of failure, there was also an audible change in sound from the steady buzzing to a crackle.

He had no experience of the "meggar" type insulation test but from limited knowledge of this method it appeared there would be difficulty in determining the exact location of any defect.

In particular it would not be possible to test internal plates such as the distilling condenser sides and base and the demister support plate. In requiring the vessel to be filled with a conducting fluid and consequently sealed the method must be more time consuming and costly than spark testing.

Referring to the question of a fibreglass shell, the company had manufactured a shell in this material some years ago. This had initially appeared very satisfactory, but over a period of time it became apparent that minute air bubbles had become trapped between the layers of glass fibre and in due course the constant raising and releasing of vacuum caused the air bubbles to expand forcing the layers of glass fibre apart and eventually destroying the shell.

It was interesting to compare the figures given by Mr. Woods with those given earlier in the discussion. He had quoted a chemical suppliers figure of £0·04 per tonne for feed treatment against an average figure of £0·032 from actual usage, an increase of 25 per cent which, considering the sources seemed reasonably consistent. His figure for maintenance however (for which no source was given) at £0·33 per tonne was 550 per cent higher than the average figure of £0·06 from actual usage. Examination of the company's spares records indicated the lower figure to be more accurate so one must assume that Mr. Woods' figures were taken from one bad example or the plants were of the type fitted with the obsolescent self scale shedding elements which were not only extremely expensive to replace but also to repair.

The figures for electrical power for a single effect plant were also high. Such a plant, either steam or hot water heated, producing 1 cubic meter/h would require only some 13 kW of electrical energy. The figure of 40 kW was, therefore, some 300 per cent high for this type of plant.

Having made these comments it was obvious that the major part of the cost was attributable to steam and power and consequently to oil costs which as we are all too well aware had increased fourfold in a relatively short period making all other costs relatively insignificant.

The most relevant overall figures were of course those for the single effect high vacuum plant utilizing diesel engine jacket cooling water and L.P. bled steam as the heating medium these being £1·01 and £2·00 per tonne respectively, or £0·73 and £1·72 per tonne respectively if the lower maintenance and chemical costs were accepted.

Using the accurate figure for power consumption, these figures were further reduced to £0·30 and £1·31 respectively, and effectively demonstrated that where engine jacket cooling water was available it was easily the most economic method of producing distilled water — see Fig. 13.

Turning now to the single effect plant discharging vapour into a condensate circulated distiller this plant had a very high thermal efficiency the only losses being the sensible heat discharged in the distillate and brine and the difference in the replacement factors of the L.P. heating steam and the vapour being discharged to the condensate system. If use was again made of the lower maintenance and chemical costs the equivalent flash plant would require a ratio of 9·0/1 and by carefully choosing the parameters the required ratio can be shown to be as high as 10·0/1. There were, however, problems with the concept:

1) The distilling condenser must be placed in the feed system after the air ejector, glands condenser and sometimes L.P. heater/drain cooler, thus the temperature of the cooling condensate was much higher than the equivalent sea water cooling temperature resulting in higher boiling temperatures leading to more severe scaling.
2) In using the L.P. bled steam extraction point, to maintain the thermal efficiency, in conjunction with the relatively high condensate temperature the overall plant terminal temperature differences were small, resulting in very large and expensive plant for a given output.
3) The plant was only viable when the vessel was operating at normal power. At reduced power the condensate quantity was reduced giving a higher outlet temperature from the distilling condenser, and the pressure from the L.P. bled steam extraction point was also reduced, thus bringing the terminal temperature differences even closer together and severely restricting the obtainable plant output. At anchor, of course, the plant was not available.

Plants of this type were seldom encountered today except in exercises to prove the viability of a steam cycle. Like the double and triple effect plant, they had been superseded by the better availability and more favourable scaling characteristics of the flash plant.

In terms of sea water distillers standard steam conditions were normally taken as 1·4 bar dry saturated. The left hand side of the two stage flash plant balance shown in Fig. 8 was correct at this steam condition. Perhaps Mr. Woods had neglected the specific heat of sea water in his calculations.

Mr. Hill had provided figures giving an indication of the considerable reduction in water carrying capacity that has been afforded by the greater reliability of the modern sea water distiller. He had also given an accurate historical description of plant traditionally fitted to both steam and motor ships. Plant of this type had certainly been very highly rated, the motor ship plant in particular, due to its low utilization factor, being normally rated on clean tube conditions only. Plant then altered in concept and interim designs with so called self scale shedding elements had double the heating surface for the same output rating. On development of the modern sea water distiller surfaces doubled again. The author would submit that in increasing heating surfaces fourfold, or in the case of hot water heated plant sixfold, distiller designers could not be accused of over-rating the product.

The questions regarding anchor operation of the hot water heated plant, correct design of pipework and repair of ebonite lining had already been discussed.

He had already commented on the advantages of the water operated brine and air ejector but would suggest to Mr. Donker that the introduction of the demister type vapour separator was of at least equal importance in achieving reliability and consistency in sea water distillers.

The premise of a spare heating element was acceptable only for replacement of elements which were in some way damaged or had been allowed to become so heavily scaled that manual de-scaling was necessary.

Acid cleaning could not be carried out by immersing an element in a tank; acid circulation was necessary and this could only be satisfactorily achieved with the element *in situ*. Where a planned regime of regular acid cleaning was carried out the out-of-service time could be less than that required to change a heating element when one considered that large diameter steam or hot water pipe joints had to be broken and remade in addition to the element joints. The author would not dissuade any owner from carrying a spare element but to his knowledge only owners with at least six similar plants had considered it worthwhile to carry even a depot spare.

He would agree that the necessity for remote starting was debatable. His personal preference was for manual start/stop of sea water distillers — which were then, of course, fully automatic in operation — basically to ensure that all isolating valves were fully open.

Mr. Haddow's contribution had added some flexibility to the discussion. He had given a welcome expansion of the necessarily brief description originally included. Mr. Gilchrist did not intend to comment further on this contribution other than to endorse the need for adequate preparation of the steel shell before being presented to the rubber lining process. He would also confirm that the quality control departments of their respective companies had maintained a close liaison to ensure that the necessary standards were not compromised.

With regard to Mr. Jenkinson's written contribution it was true that cheapness should never be the criterion in the choice of sea water distillers. Unfortunately, manufacturers of auxiliary machinery had to sell to a shipbuilder and then satisfy a shipowner. In the modern market place the shipbuilder wished to series-produce standard ships and appeared to believe that the cheapest was acceptable. As stated earlier it was necessary for the shipowner to prepare his specification in such a manner that the machinery fitted would fully meet his requirements of quality, reliability and performance.

Mr. Hewison's written contribution was particularly welcome coming as it did from a seagoing engineer with first hand operational experience of the subject.

Mr. Gilchrist was surprised by the statement that the conductivity monitoring system did not operate exactly as desired since Mr. Hewison then described how the system was in fact working perfectly. A conductivity meter, by definition, meters conductivity and cannot be actuated by turbulence in the manner described. Where a conductivity probe was inserted into turbulent conditions the reading was always low, usually zero, not high. The condition described was, in fact, due to the action of the distillate pump restarting coupled to a demister operating at the limit of its effectiveness. As any engineer was aware, one of the quickest methods of raising vacuum in a closed vessel was to fill it with liquid then pump the liquid out. When the distillate pump was running the level in the suction pipe is some 0·5 metres above the pump suction; when the pump was stopped the level rose to the top of the suction pipe or perhaps into the bottom of the distilling condenser.

On restarting of the distillate pump this liquid was discharged and caused a small, almost instantaneous, increase in vacuum which could produce a prime and restop the distillate pump if the demister was at all suspect. Reasons for the demister operating near the limit of its effectiveness might be incorrect fitting, scale reducing the surface area, or plant operating in very cold sea water conditions. The action to be taken in the first two instances was self evident, in the third the circulating water could be restricted slightly to marginally reduce the vacuum.

Feed strainers and ebonite lining repair had already been dealt with. There had been no great incidence of damage in the flange area but it could conceivably be due to over-tightening of the fastenings.

The use of ebonite lining in the shell and covers had certainly transferred the effect of electrolytic action, not corrosion, to other areas, usually pipework, either internal or external to the plant, dependent on which was the less noble. Mr. Gilchrist did not understand the reference to a bend downstream of item K which was the conductivity probe and was fitted at the junction of the vertical and horizontal distillate suction pipe. This junction was situated as close as possible to the sump suction flange with no intervening bends.

He had already discussed instrumentation but not sight glasses. Inspection windows and electric light fittings were traditionally fitted to sea water distillers but were of limited value and a source of air leakage. After a very short period of operation a layer of scale built up on the window, completely obscuring the view and requiring shut down of the plant, with attendant loss of production to clean the window if this was considered to be necessary. If considered unnecessary then the logical step was to dispense with the fitting and the inevitable air leak.