DISTILLING PLANTS IN THE ROYAL NAVY

BY

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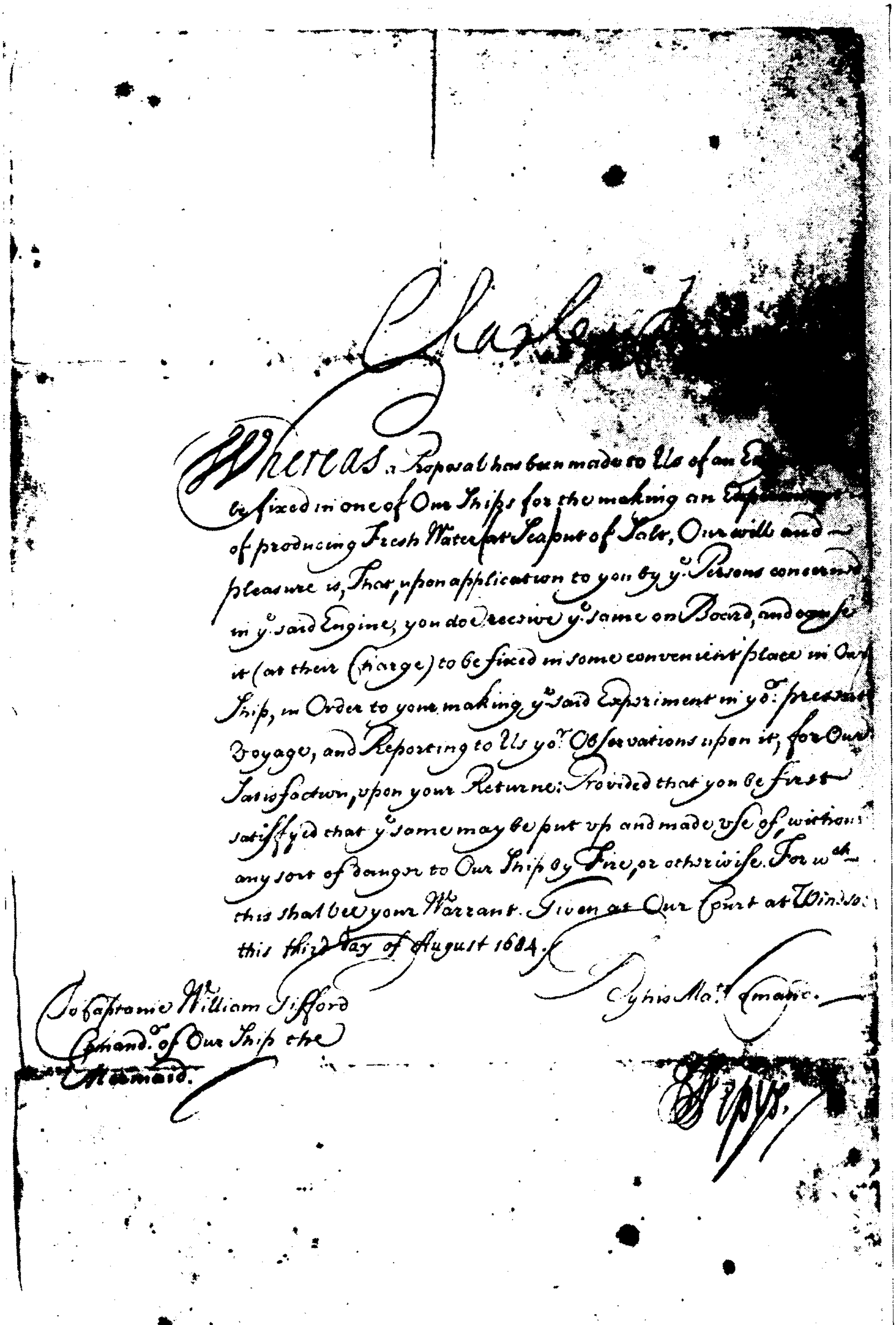
Introduction

The naval interest in distilling plants began as far as is known, in Pepys' time with an instruction to *The Mermaid* in 1684—see FIG. 1. This paper will take up the story 270 years later and bring it up to date by describing the plants in use and how they have been improved over the past 15 years. Some notes on the Admiralty Distilling Experimental Station and its activities are followed by a statement of development policy with a brief description of naval interest in reverse osmosis.

The manufacturers of naval plants concerned have kindly agreed to the use of the illustrations shown in this paper. Official Royal Navy policy is not necessarily reflected by the research and development proposals or by any opinions expressed. The author is indebted for much information and constructive criticism to the Officer-in-Charge of the Admiralty Distilling Experimental Station, Lieutenant-Commander R. N. Jackson, R.N.

Naval practice has changed from one of providing new evaporators for every class of ship, designed as a collection of components and fitted individually, to one where a package plant of known size is offered to the ship designer. This eases the design problem for shock requirements and makes development ashore more relevant to the ship plant. The whole package can, if necessary, be mounted on rubber pads to give noise and shock insulation.

Steam propelled ships require continuous supplies of high purity feed water for the boilers and, in return, supply exhaust steam as a convenient heat source. The introduction of Diesel and, later, gas turbine propulsion affects this role, for although water production for the crew is essential, a breakdown in supply lasting perhaps 20 hours can readily be contained by reserves in ships' tanks. Purity requirements too can be relaxed to those of potable water with some reduction in size and cost of the plant. A change in ship deisgn philosophy on water production is therefore imminent since it is currently grounded in the steam propulsion tradition. In this, the evaperator is an integral part of the



Charles R.

Whereas a Proposal has been made to Us of an En
be fixed in one of Our Ships for the making an Exp
of producing Fresh Water at Sea out of Salt, Our will and
pleasure is, That upon application to you by ye Persons concerned
in ye said Engine, you doe receive ye same on Board, and cause
it (at their Charge) to be fixed in some convenient place in Our
Ship, in Order to your making ye said Experiment in yor present
Voyage, and Reporting to Us yor Observations upon it, for Our
Satisfaction, upon your Returne: Provided that you be first
satisfyed that ye same may be put up and made use of, without
any sort of danger to Our Ship by Fire, or otherwise. For wch
this shall be your Warrant. Given at Our Court at Windso
this third day of August 1684.

By his Matys Command.

S. Pepys.

To Captaine William Gifford
Commandr of Our Ship the
Mermaid.

FIG. 1

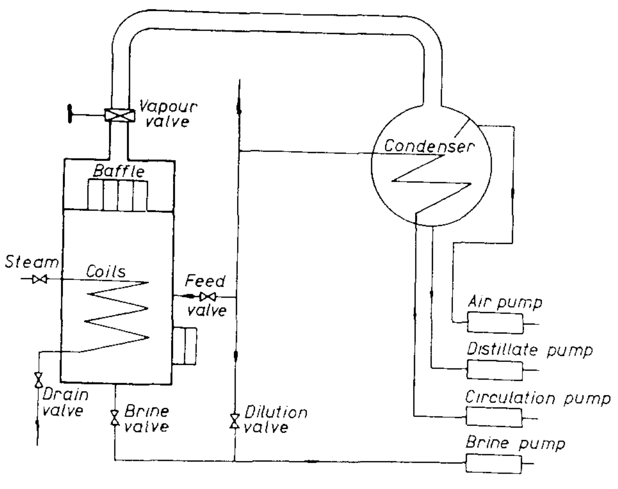


FIG. 2—EARLY EVAPORATOR

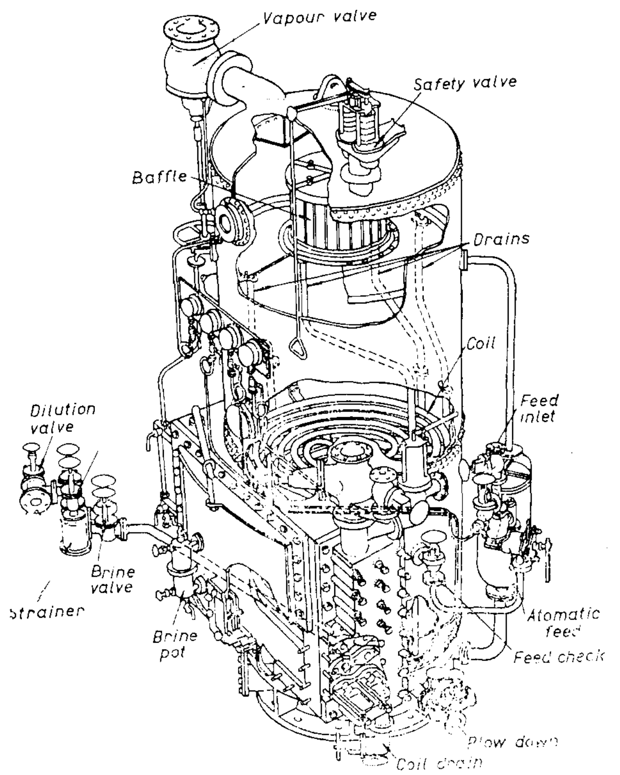


FIG. 3—EARLY EVAPORATOR

propulsion system and sufficient redundancy is specified to ensure continuous and adequate supplies of process water. The requirement of the future is to provide potable water to the crew for minimum space and cost with sufficient spares or redundant components to limit maximum likely breakdown to a short period. Although steam will be available in ships for some little time ahead, the incentive to dispense with it entirely is very strong.

Space limitations have precluded detailed arguments or descriptions. This rather stark outline gives the state of the art, the general problems ahead and the plans for dealing with them.

PLANTS IN SERVICE

Submerged Element Plants

These plants are the traditional and most widely employed at this time. Sea water is heated and boiled in the same vessel or shell and is then condensed in a condenser. The means of heating is by passing steam or hot water through coils or a monel element submerged in the boiling brine. Improvements have been included in new designs or back-fitted onto older plants where the potential advantages have justified it. They have all made a contribution to improving control, rated output or reliability, and are described below.

As a starting point for description, imagine a single gunmetal shell with steam heated copper coils supplied from a saturated or auxiliary exhaust steam range. A pipe from the top of the shell leads the vapour to a condenser, the condensate is pumped away. The six controls are all hand adjusted valves which are shown in systematic relation in FIG. 2 and bear a close resemblance to those on the plant shown in FIG. 3. This evaporator with careful setting up and continuous attention will work satisfactorily for 20 hours a day, by which time the scale on the heating coils begins to affect output and blowing down becomes advisable. Difficulty in running this plant can be imagined, for the heat input, i.e., steam and drain valve settings, and the feeding and brining rate have to be balanced to give rated output with a brine density twice that of sea water. No two watchkeepers ever had quite the same method of arriving at their own unique solution.

Modifications carried out to improve this type of plant include:—

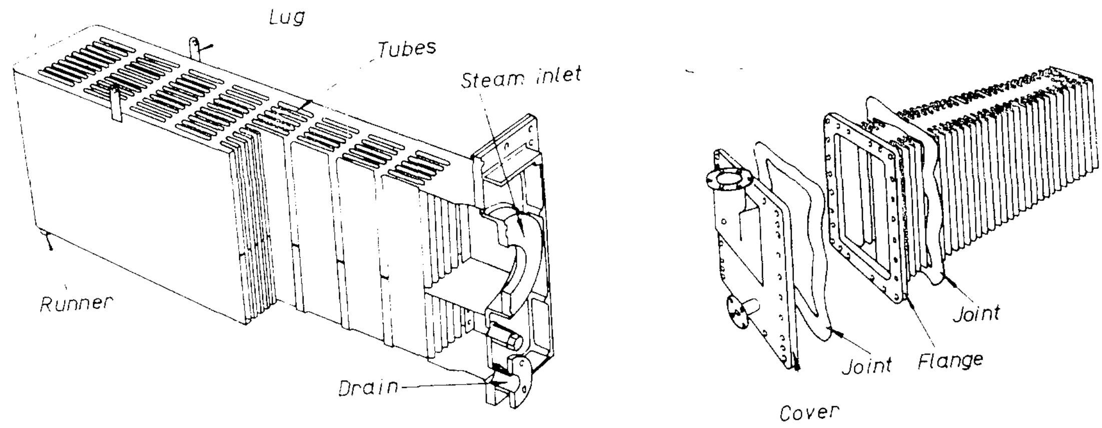


FIG. 4

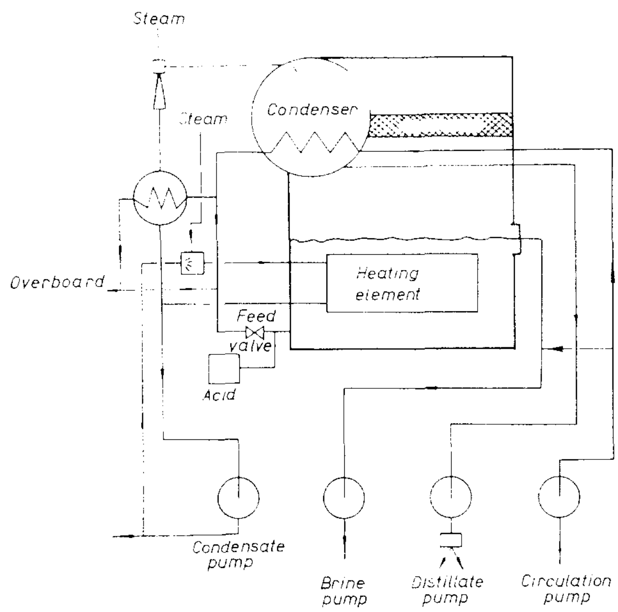


FIG. 5—RECENT MODEL

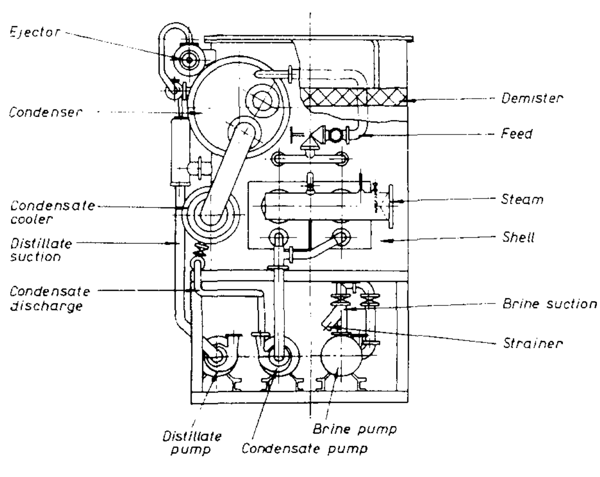


FIG. 6—RECENT MODEL

(*i*) Heat input control by critical orifice in the steam supply line which curbs the watchkeepers' desire to force the plant and simplifies his control task.

(*ii*) Brine level control is simplified by placing a weir at the desired brine level in the brine suction, thus making a single feed valve control the brine density.

(*iii*) Reduction of the scale problem (originally by various organic feed treatments to make the scale friable) by the use of flexing submerged elements which shed scale by flexing as their temperature varies, or by acid feed treatment which lowers the brine pH sufficiently to keep the scale-forming salts soluble. Illustrations of flexing elements are shown in FIG. 4. Temperature gradients are minimized by using low pressure de-superheated steam which further reduces scaling.

(*iv*) Reduction of carry-over by employing wire mesh demisters instead of slat baffles in the vapour stream. Since the demister

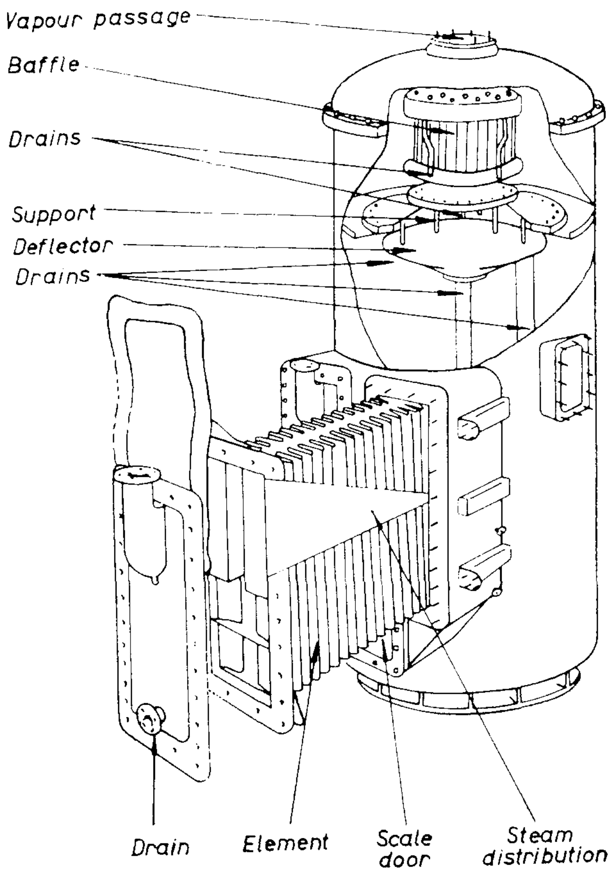


FIG. 7—ONE SHELL OF PLANT FITTED IN GP FRIGATES

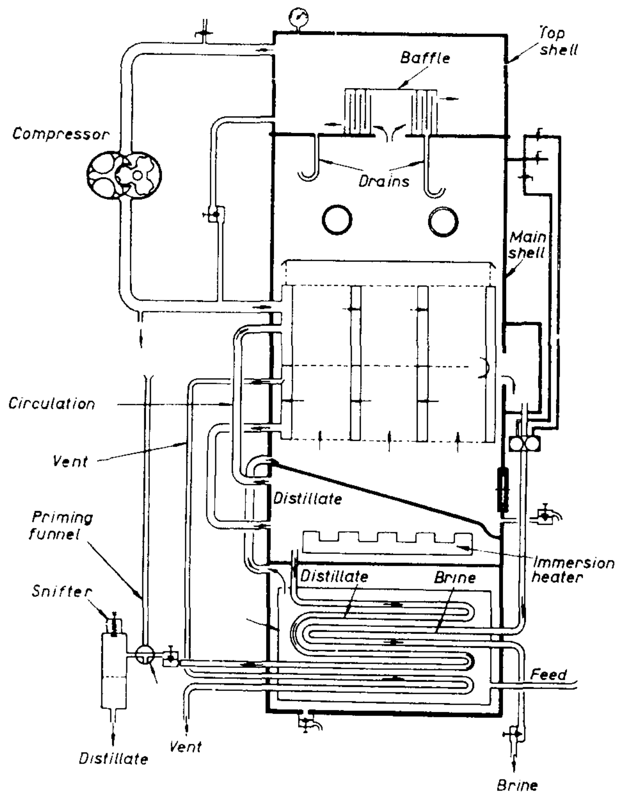


FIG. 8

is effective over a much wider range of vapour velocities, control is simplified and frequently output at acceptable purity is increased.

(*v*) The replacement of vertical combined pumps by individual horizontal coupled pumps, and of air pumps by steam ejectors has improved maintainability and reliability

(*vi*) Introduction of a salinometer operated dump valve on the distillate discharge to improve quality control and ease watchkeeping.

(*vii*) Compactness and higher shell vacuum is made possible by dispensing with the vapour valve and mounting the condenser at the top of the evaporator shell.

(*viii*) Arranging the components on a single bedplate to make a standardized package, improving accessibility and control.

A plant including all these improvements is shown diagrammatically in FIG. 5 and closely resembles the plant shown in FIG. 6.

Variations on the main theme occur in ships with limited steam supplies when vapour from the first shell is fed as heating steam to the second shell. This increases the output per pound of steam but at some cost in weight and space. An evaporator of this type is shown in FIG. 7.

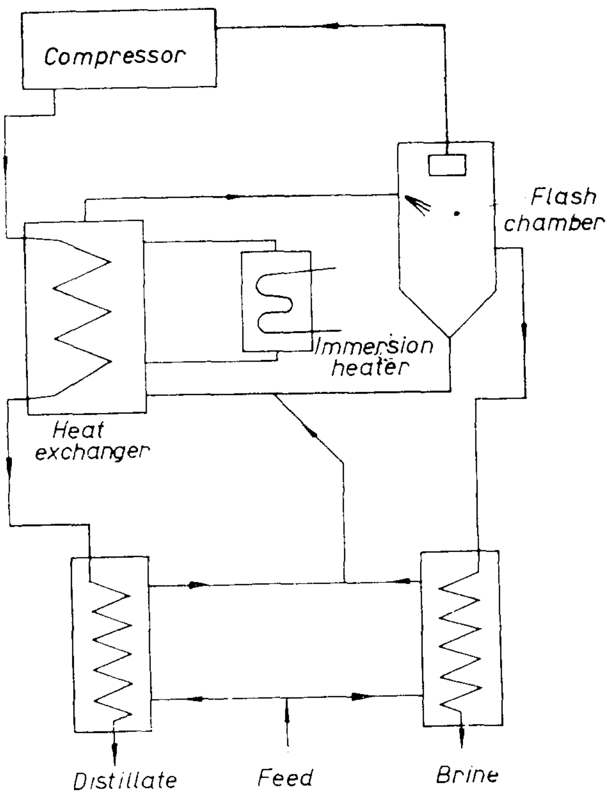


FIG. 9

Vapour Compression Distilling Plants (VCD)

This type of plant employs a compressor to draw a slight vacuum in the evaporator shell and compress the vapour, which is discharged to and condenses in a heat exchanger submerged in the brine. The latent heat and compressor work, supplemented by an immersion heater, sustain boiling.

VCD plants are used in conventional submarines and in the Diesel engine propelled frigates.

Submarine VCD Plants (FIG. 8)

Developments through a number of types have raised the output to 18 gallons an hour with sufficient reliability for one plant per vessel to suffice. The latest specification includes:

Gear wheel pumps for brine and distillate.

Facility for descaling a compressor in place with citric acid.

Automatic shutdown in the event of an overloaded compressor or heating element.

Diesel Engine Propelled Frigate VCD Plants (FIG. 9)

These plants have suffered all their lives from compressor drive troubles occurring in the epicyclic step-up gearbox which couples the motor to the centrifugal compressor. Some of the plants have heating coils and employ acid feed treatment, while others are fitted with flexing elements. To achieve a reasonable output they are run at a high brine density and high temperature resulting in scale and control problems.

Although economical in power consumption, submarine and frigate VCDs are large, heavy and complicated for their output. It is unlikely that this type of plant will be specified for future surface ships.

Flash Distillation Plants

Flash plants differ from submerged element plants in that the full cooling water flow is used as feed and heating takes place separately from evaporation.

They were introduced comparatively recently after trials at the Admiralty Distilling Experimental Station (ADES) and at sea. The advantages in steam economy, long scale life and stability offered a substantial advantage over the submerged element plants available at that time (early '60s). After putting five four-stage plants to sea and having experience of two-stage and four-stage plants at ADES and in H.M.S. *Anzio*, a decision was made to standardize naval requirements into three sizes of packaged two-stage flash evaporators. These are: seven ton/hr, two ton/hr, and one ton/hr plants. A summary of the design features of the two ton/hr plant is given below:—

(*i*) The feed flow is controlled automatically to maintain a fixed top temperature of maximum value 175 degrees F (79 degrees C), the flow is once through;

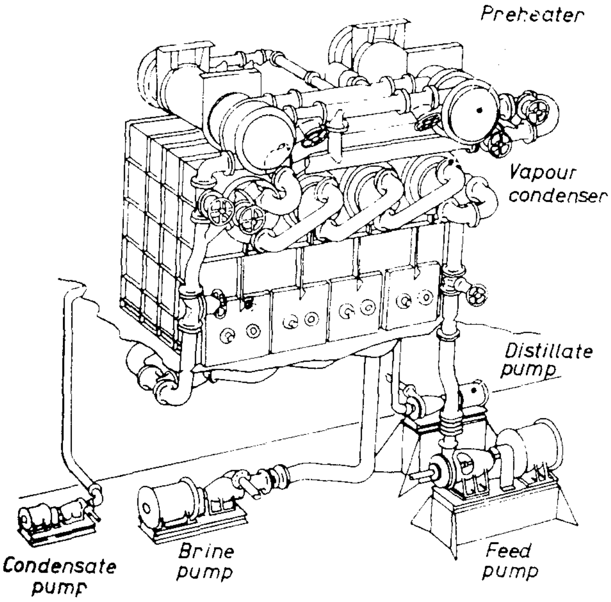


FIG. 10

(*ii*) The heat input rate is kept constant by supplying steam at a constant pressure through a critical orifice;

(*iii*) The final heater runs under a vacuum on the steam side, the pressure of which will rise as the heater becomes scaled and the advisability of acid cleaning is indicated when this pressure approaches atmospheric;

(*iv*) The flash chamber vacuum is maintained with a steam air ejector;

(*v*) The air ejector condenser is mounted above the final heater and is drained to it;

(*vi*) Distillate and drains are dumped automatically at a pre-set conductivity level;

(*vii*) The plant shuts down automatically in the event of component failure;

(*viii*) All components are mounted on a single bedplate to form a standard package and individual pumps are used.

These designs were intended for steam propelled ships—now their future in gas turbine vessels seems more likely, with heating from an auxiliary boiler. It would be feasible to modify these plants to take heat from Diesel jacket cooling water and this would offer a good return by reducing the fuel and water requirements of the ship.

Automatic water temperature control by pneumatics was chosen because pneumatics are widely used in steam ships. This means of control is more precise than is necessary and the equipment is expensive and bulky.

A drawing of the four-stage Buckley and Taylor plant fitted in H.M.S. *Fearless* is shown in FIG. 10, a diagrammatic two-stage flash plant in FIG. 11, and a control circuit block diagram in FIG. 12.

Salinometers and Dump Valves

Recording salinometers have been used since the mid-'40s with modest improvements in detail design. The adoption of in-line probes and the coupling of dump valves to the salinometer completes the picture. There is room for improvement in probe reliability.

Six probes are used on the flash plant to aid fault diagnosis. Experience may show that fewer probes are adequate.

Dump valves at present employed are directly operated by solenoid. The reliability has not been at all good in practice, because the solenoid is only just powerful enough when the valve is new and clean. Some experience at ADES with a solenoid operated servo, employing the fluid pressure to move the valve lid, is promising.

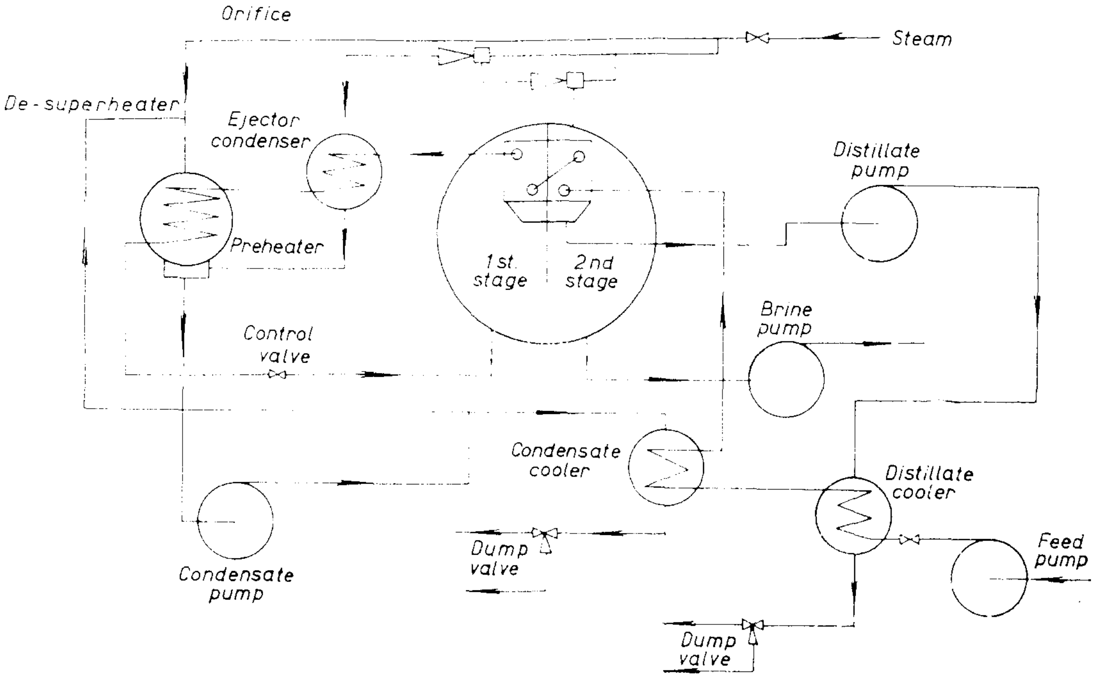


FIG. 11

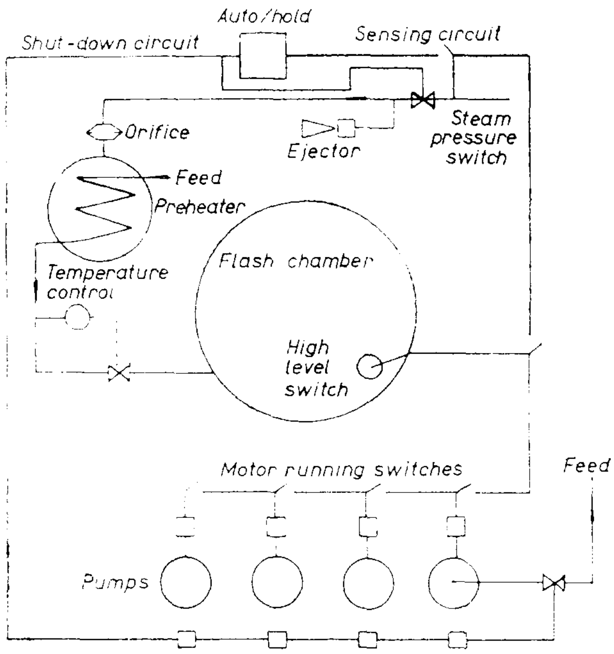


FIG. 12

SCALE PREVENTION AND REMOVAL

Feed Treatment Equipment

This consists of a tall 25-gallon plastic tank equipped with a lid and stirrer in which chemical solutions may be mixed. A plastic tube leads to an injection nozzle downstream of the feed control and a throttle valve regulates the flow. Injection is normally by vacuum drag and the throttle valve is set by timing the rate of fall of the chemical tank level. In vapour compression plants an injection pump is necessary because boiling is at or just below atmospheric pressure. Experience with metering pumps suggests that vacuum drag is a more consistent, as well as a simpler, system.

The standard feed treatment in coil submerged element plants was, until recently, by ferric chloride and, on some low temperature plants by 'Hagevap'. These have now been replaced by citric acid which has some attractive advantages over ferric chloride for shipboard use in that its milder corrosive properties render it harmless when spilt and safe to handle.

Feed Treatment in the Future

As far as flash and Diesel jacket plants are concerned, no feed treatment is planned.

For steam heated submerged element plants, citric acid feed treatment will be used.

Electrical generation of acid in the feed supply is being investigated, primarily because of its logistic attractions.

Distilling at Low Temperature

The use of Diesel jacket water as a heat source has brought to the fore the need to distil at high vacuum in order to get satisfactory temperature differences between the heating element and the brine. This, combined with satisfactory control of the brine concentration, gives a low scale rate which will enable small ships fitted with this type of plant to run for long periods without acid cleaning and without needing feed treatment. A boiling temperature of 120 degrees F (49 degrees C) is sufficiently low to achieve this.

Reduction of Heating Element Temperature

A small high temperature heating element, while simple to make and fit into a plant, has a poor scale life. This is because it induces a high brine temperature and salt concentration in the boiling brine immediately surrounding it. (In flash plants there is no boiling and so no concentration effect.) The lower the temperature of the heating element can be reduced, the better the scale life, but there is a practical limit in supplying sufficient area of element for reasonable plant output. The compromise chosen, is for element steam temperatures to be:—

(*a*) Flash plants about 190 degrees F (88 degrees C) clean to 210 degrees F (99 degrees C) dirty;

(*b*) Submerged flexing element plants 217 degrees F (103 degrees C) clean to 230 degrees F (110 degrees C) dirty on the more modern plants.

Flash plants run up to 2000 hours without descaling, while the flexing element plants need to be descaled at 500-hour intervals if excessive calcium sulphate scale is to be avoided. To reduce steam temperature sufficiently for use in these plants it is necessary to expand the steam and desuperheat it. An element drain pump removes condensate from the element and returns some of it to the steam supply by means of a spray. Precise spray control is not necessary so long as the amount of water sprayed into the steam is more than sufficient to ensure saturation.

Brine Density Control and Scaling in Submerged Element Plants

The precipitation of magnesium hydroxide and calcium carbonate as a result of heating can be mitigated by minimizing the boiling temperature and that of the heating element and lowering the pH of the brine by acid feed treatment. The problem of calcium sulphate scale, however, is chiefly dependent on the concentration of salts in solution, which is a function of the density ratio between the feed and the brine. If sulphate scale is to be avoided completely, brine density should be kept at or below 1·5 that of sea water. As little as 12 per cent calcium sulphate in the scale may render it impervious to acid cleaning fluid and an element so scaled has to be cleaned by mechanical means.

Naval plants are designed for a brine density of twice that of sea water feed and this, in fact, is satisfactory.

Coil element plants with acid feed treatment run for long periods without any deposits of scale at a brine density of two, whereas flexing element plants do scale and require regular acid cleaning. At present acid feed treatment is not used with flexing element plants but there may well be a case for doing so. Trials to determine this are planned.

Acid Descaling

Inhibited hydrolochoric acid is used in a 10–12 per cent solution with fresh water. The mix is made up in the shell by adding acid to water with a special hand pump.

In some plants circulating connections to the brine pump are fitted and in the case of flash plants a special circulating pump is provided. In the older plants, however, the acid is left for 20 hours just covering the heating element and then diluted with sea water and pumped out. If scale is still present a repeat performance is carried out and if the condition is still unsatisfactory removal of the element and mechanical descaling is necessary.

ADMIRALTY DISTILLING EXPERIMENTAL STATION

General

The Admiralty Distilling Experimental Station was created in 1950 after a good deal of sea water prospecting. The need for clean mid-ocean quality sea water near to human habitation has been better met at Portland than surveys showed likely in the rest of the south of England. The dissolved solids in the sea water at Portland are approximately 34 000 parts per million (ppm). The Eastern Mediterranean has 39 000 ppm, the Atlantic varies between an ice cap value of 32 000 ppm, to a maximum of 37 000 ppm nearer the Equator and Troon has 32 280 ppm.

The early objectives were to run conventional evaporators with various feed treatments to assess their efficacy. It was not long before some development work started. This really got into its stride in the late '50s with basic work on flash evaporators and now the programme of trials and development stretches heavy laden for some years ahead. To enable ADES to meet these commitments, a new Test House is being built alongside the old one which will allow more trials to be run simultaneously and provide better access to the plants on trial. Shift working is normal which keeps plant utilization high and cost per hour of trials low.

Trials

When a prototype arrives for trials at ADES, it has already done shop trials and met its specified performance on synthetic sea water. The requirement at ADES is to run the plant for longish periods under a variety of conditions in order to identify its weaknesses.

The scale life under normal conditions, the ease of descaling and component reliability are fairly clear after about 4000 hours' running. A maintenance exercise is carried out to assess removal, examination and replacement of selected components.

By recirculation of the brine, a flash plant may be run under simulated extreme tropical conditions, i.e., feed at about 37 000 ppm, and 95 degrees F (35 degrees C), and any intermediate condition down to once-through feed flow at the prevailing sea temperature and density of 34 000 ppm. By determining the maximum and minimum output at acceptable salinity for various feed temperatures, a performance envelope can be drawn which shows the plant's idiosyncrasies and spare capacity.

Development of Automatic Controls

The decision to develop automatic controls was bred from the wish to minimize watchkeeping and the simplicity with which a flash evaporator lends itself to control. Pneumatic feed temperature control was fitted to a plant which ran with no real problem. Deliberate mishandling of the plant produced no misdemeanour and it is considered that this control system is, if anything, too good. Use of a more conventional thermostat is planned for this duty.

Automatic shutting down of the plant is necessary. This provides for shutting down of steam supply, all pumps and the feed water supply should any of the following occur:

(*a*) High steam pressure supply to the orifice control;

(*b*) Any pump motor failure;

(*c*) Flooding of the last flash chamber;

(*d*) Feed pump failure.

A salinonmeter operated dump valve diverts both distillate and condensate if a certain level of conductivity is reached.

Trials controlling steam flow instead of feed flow were satisfactory but are less appropriate to a marine plant.

Sterility of Distilled Water

Current practice requires that the brine is heated to 162 degrees F (72 degrees C) when distilling in harbours or estuaries, and ships are provided with means to chlorinate the fresh water tanks.

Conventional submerged element and flash plants operate on the safe side of this limit and so there has so far been no great incentive to look more closely into the problem. The introduction of low temperature Diesel jacket plant has entailed the provision of a distillate heater to meet the temperature limit, which is costly, bulky and wastes heat.

A series of trials performed jointly by ADES and the Royal Naval Medical School started in early 1967 to establish sufficient data to review current practices.

Essentially, these consist of running a variety of evaporators under varying conditions, infecting the sea with a sewage concentration of bacteria, and sampling temperature and infection at a number of points in the process. A great many trials have now been run and the experimental techniques are consistent and satisfactory. Further trials are necessary because a minimum sterility temperature has not yet been established. However, there is sufficient evidence for an interim report, which is being prepared.

Broadly, the first conclusion is that under boiling conditions pathogenic bacteria do not survive in brine above 120 degrees F (49 degrees C). Thus there is no danger of infecting distillate by way of the distillation process when operating the plant above this temperature. There is some reason to believe that the lower limit may be further reduced when modifications to the equipment allow distillation at lower temperatures.

The second and more significant conclusion is that the major danger has always been that of post-process infection from a leaking condenser or distillate cooler tube.

In the past, the preoccupation with producing boiler quality water (i.e., less than 4·5 micro mho conductivity) has reduced the likelihood of infection, since a leak would not be tolerated. This, however, does not guarantee that a slight leak will not occur when distilling in harbour.

A number of equipments are being examined with a view to fitting ships with an easy and accurate means of sterlization when distilling inshore.

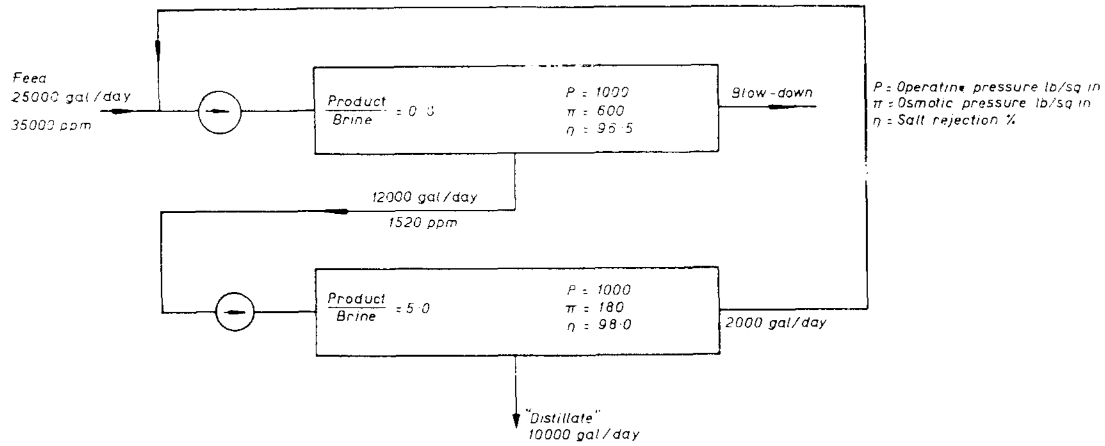


FIG. 13

DEVELOPMENT POLICY

The immediate task is to select and develop a range of plants suitable for the next generation of warships. This is well in hand for flash plants, the principal features of which have already been summarized. Diesel jacket plants will be similarly handled and this will provide the wider scope necessary for ships with no steam generating capacity. The development programme can be tailored to lead to a choice of packaged steam or Diesel jacket heated two-stage flash plants and a similar range of Diesel jacket heated single-stage submerged element plants.

Maintenance doctrine of repair by replacement and the emergence of cheap single-stage packaged evaporators raises the possibility of using commercial equipment and changing the whole package periodically. Such possibilities have an attractive cost advantage. Trials are planned on such a plant to explore the potential.

Investigation into sterility problems will continue, aiming at a satisfactory definition of safety limits and provision of a range of sterilizing equipment that can be used for distillate or shore supplied water.

For the longer term, the possibility of employing reverse osmosis plants is being closely investigated. A crucial assumption of the attractions of this process lies in the demise of steam propulsion and therefore of the need for high quality feed water. Essentially, reverse osmosis is a filtration process requiring only pumping power and feed water. The ship designer will then be faced with a much easier job in siting the plant and the operator in running it, since it will not be associated directly with a heat source. Preliminary studies show that a reverse osmosis plant of similar output but smaller in size and weight than a standard two ton/hr flash plant, with a degree of built-in redundancy giving a reliability equal to a complete spare plant, is possible. Development of higher flux membranes and more compact modules could reduce its size substantially. A more detailed design study is now in hand and a prototype is planned. Essentially, the intention is to buy the most suitable membrane available and concentrate on the marine engineering development of the pumps, filters and control gear. If and when this is satisfactory, the next step would be a seagoing plant for a trial period. A flow diagram of the planned reverse osmosis plant is shown in FIG. 13.

The specification will include:

(*a*) Feed chlorination and acid treatment;

(*b*) The ability to detect and divert the products of a defective membrane module.

CONCLUSION

Machine evolution and the changing trend in naval requirements over the past 15 years have led to a point where conventional plants have been vastly improved, flash and Diesel jacket plants are being introduced, and our knowledge of thermal distillation techniques is within sight of being very satisfactory. Just over the horizon is the strong possibility of steamless ships in which water production must either depend on using low grade Diesel jacket heat for distillation or the techniques of reverse osmosis.