DESALINATION PLANTS IN FUTURE DESIGN WARSHIPS

BY

LIEUTENANT-COMMANDER M. R. MARKS,
B.SC(ENG)., C.ENG., M.I.MECH.E., M.I.MAR.E., R.N.
(Ship Department)

Introduction

Current designs of gas-turbine-powered warships are fitted with distilling plant operated by steam. This has necessitated the installation of auxiliary boilers varying in number from two in the Type 21 frigates to five in the Command cruiser. Generally, at least one boiler is continuously required and this imposes a heavy maintenance load. By way of comparison, in a frigate with steam propulsion, the single auxiliary boiler can be expected to accumulate about 2000 hours of running in a four-year period whereas those fitted in a gas-turbine frigate are likely to achieve some 10 000 hours each in the same period.

Galleys and laundries are changing more and more to electrical equipment so that the option of a warship without auxiliary steam is becoming increasingly attractive. In keeping with this option, two types of desalination plant come to the fore: waste heat and reverse osmosis. Vapour compression plants have not been overlooked but, while thermal performance is very attractive, experience has shown that the mechanical reliability of the compressor leaves a lot to be desired. There are also noise and scaling problems.

Waste Heat Plants

Sources

There are three possible sources of waste heat in future warships:

(*a*) Main gas turbines: a large amount of energy is available but these turbines are notoriously sensitive to exhaust pressure drops and they are not available in harbour.

(*b*) Incinerator: this equipment has been investigated as a source of heat but, even in large warships, it is disappointingly low and sporadic. It is unlikely to be usable for producing much more than domestic hot water in the foreseeable future.

(*c*) Diesel generators: a constant supply of waste heat (varying, of course, with load) is available interrupted only when the ship changes to shore electrical supplies. When this occurs, it is reasonable to assume that fresh water will also be available.

Diesel Generator Waste Heat Distilling Plant

Very roughly a diesel generator splits the energy derived from its fuel equally between useful power, the exhaust gas, and the cooling-water system. The simplest form of distilling plant uses this engine cooling water to operate a single-effect evaporator. The conventional sea-water heat exchanger is retained for use when the distilling plant is not operating. Further energy input can be obtained from an exhaust gas heat exchanger, albeit at the price of a more complex arrangement, or from an electrical calorifier used as a boost when required. The latter is attractive in that it produces a dual increase in energy available both in terms of the direct heating effect and also because the increased load on the generator provides more waste heat. It can also be used to maintain a reasonable load on the generator and avoid the coking-up associated with low-load running. On the debit side, more space is required and the extra energy is reflected in increased fuel consumption.

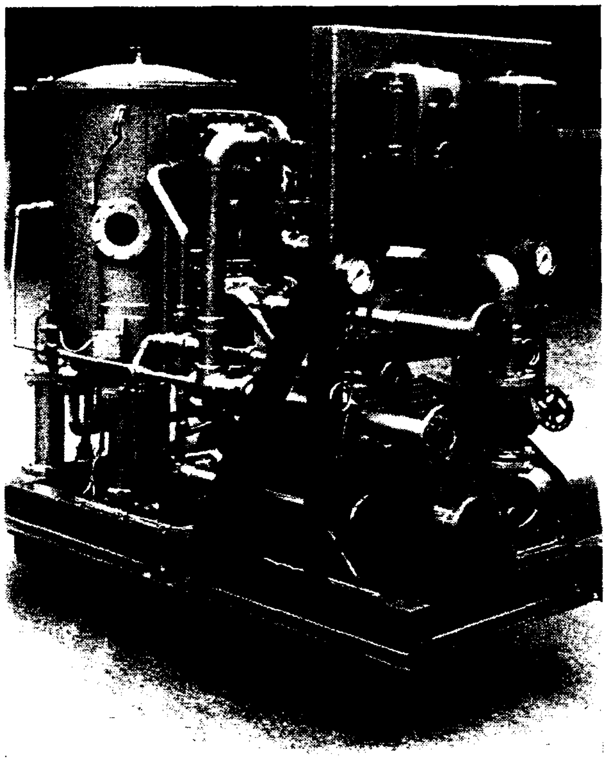

FIG. 1—A 4 TON/DAY WASTE-HEAT PLANT

Energy Availability

It can be shown that, for a single-stage waste-heat plant using only jacket water heating, it is unlikely that completely self-supporting water production (30 gallons/man/day) can be achieved unless the ship has an installed electrical capacity of at least 25 kW/man and even then actual output will depend upon electrical load factors. The introduction of an additional low-efficiency exhaust-gas heat exchanger will reduce this figure to about 18kW/man. As a comparison, the Type 42 destroyer installation has only 14 kW/man and, in fact, an investigation of a waste-heat plant fit in a vessel of this size and type showed that full design water output was not achievable with generator loads below that corresponding to normal cruising. To meet requirements in the day-harbour and night-harbour conditions, either electric boost, some assumption on the availability of shore water, or a reduction in the standard water allowance is required. As a contrast, the new seabed operations vessel (SOV), which will have a large installed generating capacity (because of its diesel-electric main propulsion) and a relatively small complement, lends itself to waste-heat plants. Its five main generators, having an installed capacity of about 70 kW/man, will each have an associated waste-heat plant capable of about 8 tonnes/day output. FIG. 1 shows a 4 tonnes/day plant of this type.

Energy Dissipation

Acquiring free energy is one problem; using it to advantage is yet another. Our experience with waste-heat plants is limited to outputs of less than 22 tonnes/day and in sea-going plants to about half that figure. A waste-heat version of the very successful Caird and Rayner 47 tonnes/day two-stage flash plant (fitted in the Type 42 destroyers) could confidently be developed but would have a maximum output of only 36 tonnes/day representing poor value for the space occupied.

From an installation point of view, it is beneficial in terms of simplicity and flexibility to have one distilling plant per generator. For the operator, this produces a very attractive degree of redundancy; for the designer a space problem. On this basis, a warship comparable with a Type 42 destroyer would require four 39 tonnes/day plants occupying considerable space. Quite obviously this situation can be improved by cross-connecting one plant between a pair of generators but this immediately introduces complexity, layout restrictions, and limits the choice of plant and generator operation. A further alternative is a waste-heat ring main which would be bulky, less efficient, and more vulnerable.

Future Trend

As always a compromise situation seems to be most attractive in the form of a one plant per generator fit using jacket water waste heat with optional electric boost. Although water output would be marginal in, for example, a Type 42 destroyer style installation, this is compensated for by flexibility and reliability.

Reverse Osmosis

Background

The article 'Reverse Osmosis' (*Journal of Naval Engineering*, Volume 20, No. 1) describes the principle of this process which, viewed simply, uses high pressure (about 65 bar) to filter sea water through a cellulose acetate membrane in two stages to produce water with about 200 ppm total dissolved solids. Reference was made to the intention of designing and building a prototype plant.

Development

In fact, three 45 tonnes/day prototype plants were built for testing. These plants used forty-eight 'R3' 110-tube modules of cellulose acetate in the first stage and six 'B9' permeators of nylon in the second stage. FIGS. 2 and 3 show the construction of the 'R3' and 'B9' respectively and FIG. 4 shows the complete prototype plant which is some two metres in height.

Two plants were installed at Portland and one at Haslar, the latter to investigate the biological effects of using creek water both on the membranes and on the final output. The results of three years testing have been quite successful, the main problems being centred around plant engineering rather than the reverse osmosis process itself. The major hurdle was the first-stage pumps which are a pair of three-cylinder reciprocating design operating with sea-water at 65 bar. Principal modifications have involved a change to Delryn (a nylon-like plastic) valves and solid ceramic pistons.

The R3 membranes themselves have a limited life and in temperate sea-water conditions this was found to be in excess of 3000 hours. At higher temperatures

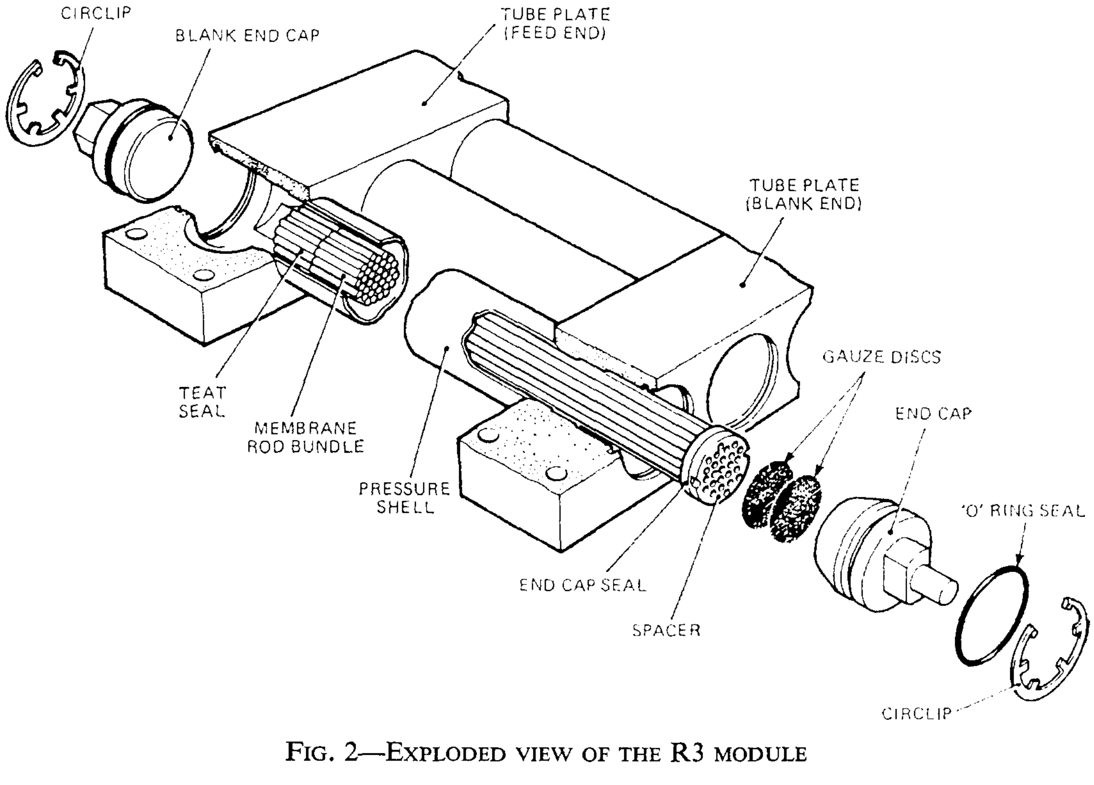

FIG. 2—EXPLODED VIEW OF THE R3 MODULE

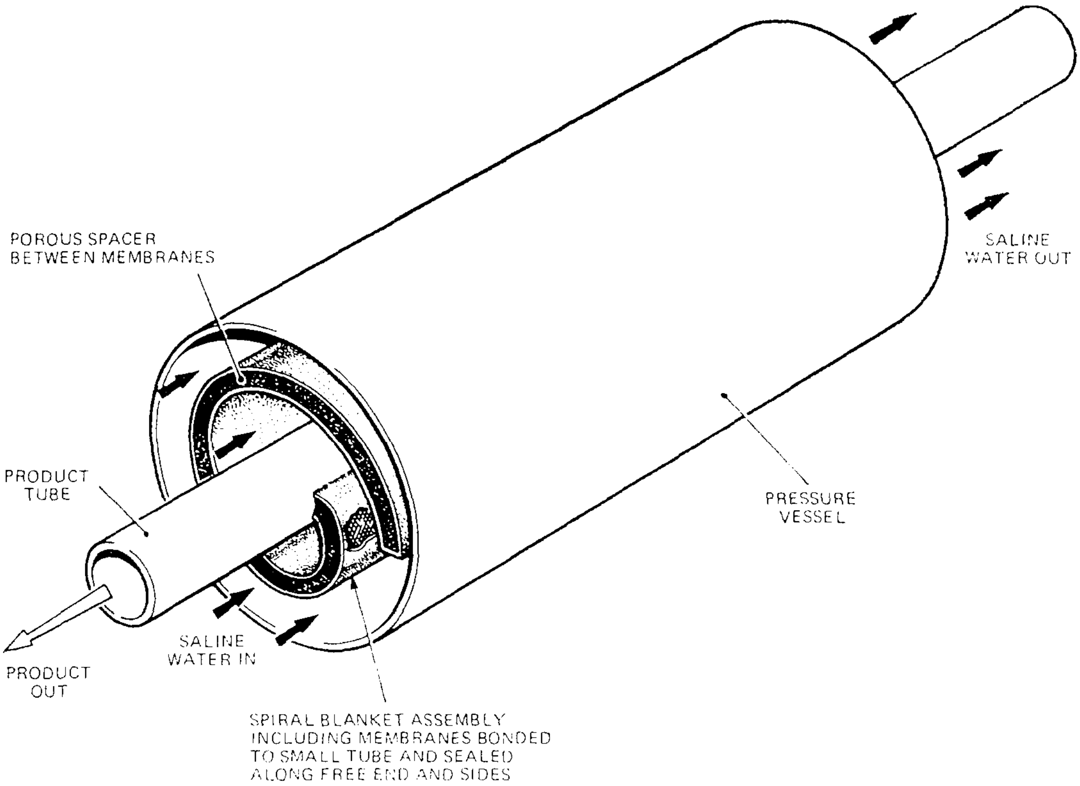

FIG. 3—SIMPLIFIED VIEW OF THE B9 NYLON PERMEATOR

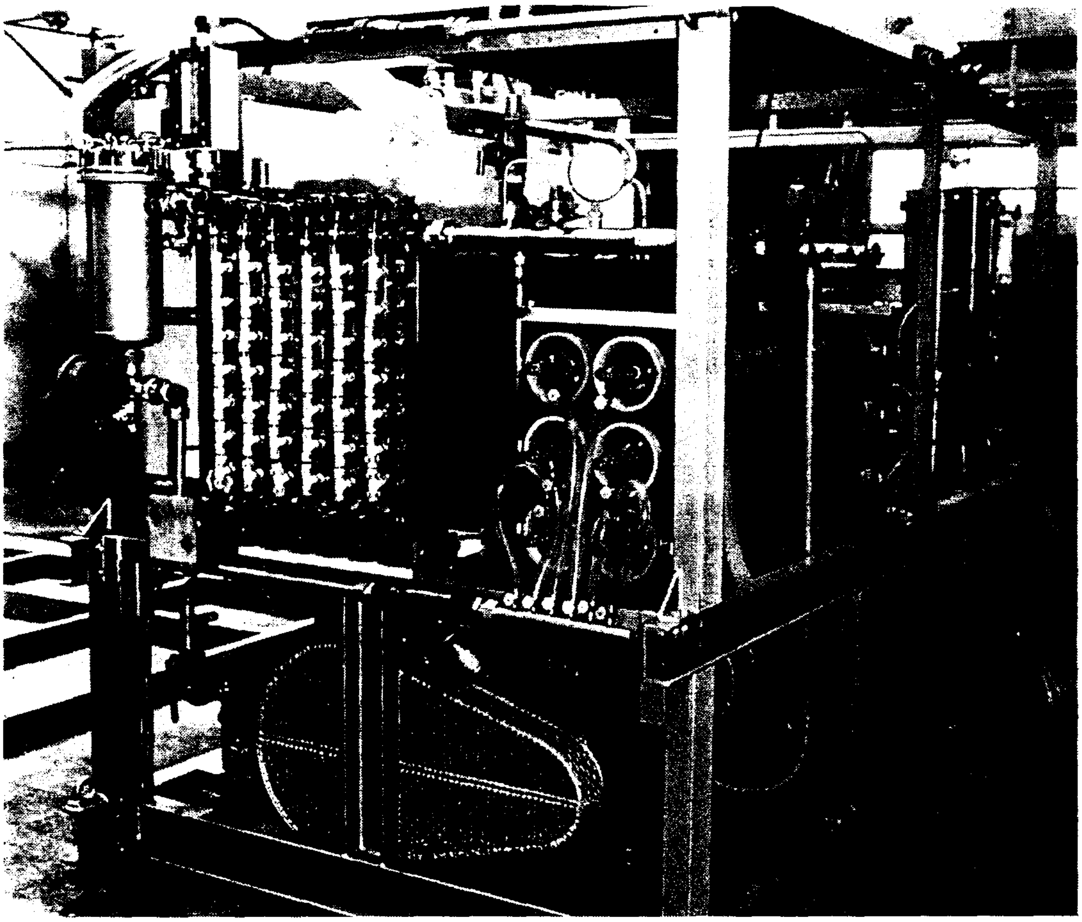

FIG. 4—45 TONNE/DAY TWO-STAGE REVERSE OSMOSIS PLANT

the life is shortened and trials to date suggest that it falls to 1000 hours at 30°C without recourse to pH adjustment of the feed designed to delay hydrolysis.

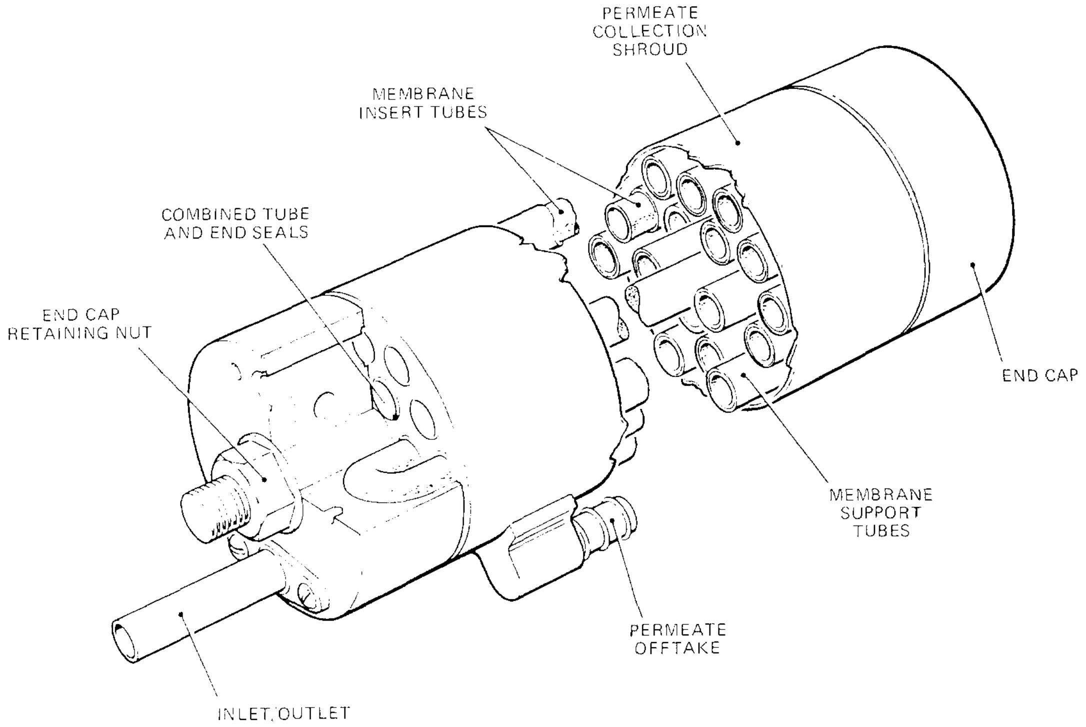

FIG. 5—EXPLODED VIEW OF THE B1 MODULE

Commercial Aspects

Recent commercial developments have led to the R3 module being phased out of production and it is proposed to replace both it and the B9 second stage with tubular modules known as the B1. This module uses the same cellulose acetate material as the R3 allowing read-across of operating experience; it comprises eighteen perforated tubes each carrying a membrane internally as shown in FIG. 5. The 12 mm bore of the membrane allows mechanical cleaning with foam balls, an operation not possible with the R3. A target life of 4–5000 hours with 10 per cent. failure has been set.

Commercial interest in reverse osmosis for sea-water purification is very limited at present being centred almost entirely round brackish water, dairy products, fruit juices, and pollution concentration. Beyond initial investigations into process suitability, the emergence of a naval plant had to await the development of a suitable, commercially available membrane. It is a matter of MOD(N) policy not to become involved in membrane development. Since then, the time has been devoted to the engineering development of systems and components.

The Future

Reverse osmosis is a viable method of producing fresh water; it is comparatively cheap to run as there is no heating process and the plant lends itself to automation. Further work is to be carried out to prove the B1 module and then to lead on to a new protoytpe which will incorporate all the lessons learned to date. The successful future of reverse osmosis plants also depends upon the continuing availability of a suitable module.

Conclusion

Waste heat and reverse osmosis plants offer advantages coupled with problems. The former employs more conventional engineering, uses free energy and offers built-in plant redundancy at the expense of space and weight. The latter is an advanced technology plant requiring further development but it is light, compact, and much cheaper on a basis of predicted through-life costs. At this juncture, it seems prudent to 'back both horses'.

It will already have been noticed that the quality of water produced by a reverse osmosis plant, whilst adequate for domestic purposes, is not suitable for more discerning requirements such as gas-turbine washing. Where the water needs of a modern ship are principally for potable water (150–500 ppm) but there is also a demand for a small quantity of high quality or process water (about 1 or 2 ppm), the requirement can most elegantly be met by a combination of reverse osmosis and waste heat. Provision of process water from potable water, even in small quantities, involves a bulky ion exchange process because of the high resin usage incurred by this degree of clean-up. The additional capacity provided by one or two small and, therefore, easily installed waste-heat plants offers a completely independent supply of process water which, in an emergency, can meet limited potable water requirements.

Acknowledgement

The author would like to acknowledge the trials work carried out at the Naval Auxiliary Machinery Department of the National Gas Turbine Establishment at Haslar and Portland and thank those colleagues who have offered advice and criticism.