REVERSE OMOSIS PLANTS FOR THE TYPE 2400 SUBMARINE AND THE TYPE 23 FRIGATE

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Introduction

The Royal Navy first became interested in the possibility of producing potable water by the process of reverse osmosis (R.O.) in the late 1960s. Trials began at ARE (formerly AMTE), Portland, in the mid-1970s, but it quickly became apparent that further advances in membrane technology were required before it would be possible to install R.O. plants at sea.

Meanwhile, pressure was being placed on the Design Sections at Bath to dispense with the need for an auxiliary steam range in warship designs, particularly with the advent of gas turbine propulsion. The subsequent investigation into alternative types of desalination plant was expanded to include waste heat plants and vapour compression distillers. However, in 1979 the awaited breakthrough in R.O. membrane technology was achieved and, subsequently, the decisions were taken to fit R.O. plants into the new type 2400 UPHOLDER Class conventional submarine and the Type 23 frigate. These decisions were made in the months immediately preceding the Falklands crisis.

This article explains the principles of R.O. desalination and then goes on to describe how lessons learned during the initial development effort and in the South Atlantic are reflected in the current designs for the R.O. installations in the Type 2400 and the Type 23.

The Principles of Reverse Osmosis Desalination

If a quantity of sea water is separated from an equal quantity of fresh water by a semi-permeable membrane within the confines of a vessel, some of the fresh water will migrate through the membrane into the more concentrated solution of sea water, causing its level to rise (see FIG. 1). The ultimate level of the concentrated solution above that of the fresh water is a measure of the 'osmotic pressure' of that solution—for example, the osmotic pressure of sea water in the vicinity of the UK is 410 p.s.i.. Conversely, if an external pressure, greater than the osmotic pressure, is applied to the sea water, fresh water (or permeate) will pass through the membrane leaving behind a more concentrated solution of sea water and increasing the volume of fresh water (FIG. 2). This phenomenon has been termed 'reverse osmosis' and is the basis of this desalination technique.

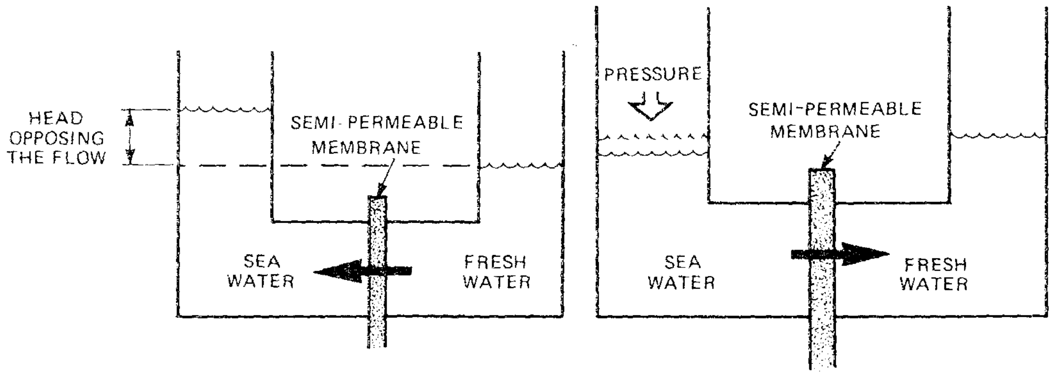

FIG. 1—NATURAL OSMOSIS

FIG. 2—REVERSE OSMOSIS

In its simplest form, a high pressure (HP) pump supplies sea water to a stack of membranes. The pressure is regulated to between 750 and 900 p.s.i. by the manual operation of a control valve on the concentrate discharge line (FIG. 3). The permeate is led away to the storage tanks and the concentrate is discharged overboard. The sea water feed can be taken either from the main service or from a LP sea water system; in the latter case a booster pump is required. It is essential that all the pipework concerned is non-ferrous as iron fouling of the membranes greatly reduces their life.

Plant operation is governed by a number of inter-related guidelines which give the operator considerable flexibility in adjusting the quantity and quality of the permeate produced:

- Permeate quality improves with increased applied pressure (Max 900 p.s.i.).
- Permeate output changes with sea water temperature (approx 3 per cent. increase in output for each °C rise in temperature).
- The recovery ratio (Permeate × 100/Sea Water Feed) should not exceed 30 per cent., to prevent the precipitation of dissolved solids from the concentrate.
- Permeate quality (for warships) is currently not to exceed a total dissolved solids (TDS) level of 1500 p.p.m.

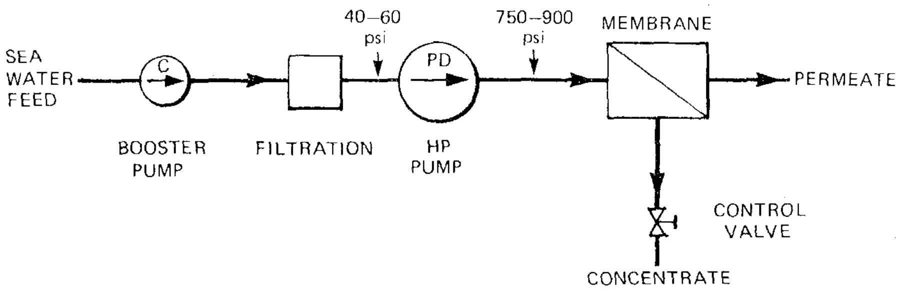

FIG. 3—BASIC REVERSE OSMOSIS PLANT
C: centrifugal PD: positive displacement

Early Development

As with so many engineering principles, whilst the theory is simple the application of the theory can present many challenges. The first problem to be overcome was to find a suitable membrane. Early trials with cellulose acetate membranes, supplied by a British manufacturer in a tubular configuration, were disappointing; the membrane proved to be unreliable, prone to chemical and biological attack, and had insufficient life for a practicable installation in a ship. Attempts to develop a non-cellulosic membrane ended prematurely when the manufacturer decided that the potential commercial market was not sufficient to warrant further investment. Other types of membrane were, meanwhile, being introduced—principally by manufacturers in Japan and the U.S.A.

The Japanese had developed a cellulose tri-acetate membrane, in a 'spaghetti' configuration, which exhibited a much higher salt rejection than its British counterpart. However, this type of membrane also suffered from the major disadvantage that it was not tolerant to a sea water feed at a normal, untreated pH of between 7 and 8. It was, therefore, necessary to dose the sea water feed with hydrochloric acid in order to reduce its pH to approximately 6 and, subsequently, to increase the pH of the permeate to within the acceptable limits for potable water, by using a mineralizer. This would introduce an undesirable increase in the plant complexity, increase the plant running costs, and require the bulk storage of hydrochloric acid on board.

During 1980, trials were begun at ARE, Portland, using a non-cellulosic membrane developed in the U.S.A. This polyamide-based proprietary membrane was manufactured in a spiral-wound configuration; it did not require acid dosing of the sea water feed, and it was more tolerant to the presence of small suspended particles in the sea water feed than the alternative tubular and 'spaghetti' configurations.

More details of this stage of the R.O. development programme are given by Owen.[1] The trials indicated that the performance of this membrane was such as to warrant the development of R.O. plants for the planned Type 2400 submarine and the Type 23 frigate. Detailed work on these designs had just commenced when the Falklands crisis broke.

The Falklands Campaign

Many of the merchant ships taken up from trade (STUFT) during the campaign and subsequently in support of the garrison, had insufficient desalination plant installed to meet the requirements of the increased ships' complements carried. Also, some of the ferries had no water-making capacity at all as they normally filled their tanks in harbour between trips. R.O. plants were, therefore, widely fitted throughout the Task Force; the story of how this was achieved was told in the last issue of the Journal.[2]

The experience gained from operating 34 plants in the South Atlantic has proved to be of immense value. Many of the lessons learned are reflected in the designs for the Type 23 frigate and, to a lesser extent, the Type 2400 submarine. Perhaps the most fundamental conclusion drawn is that it is not necessary to go to the expense and complexity of a two-stage plant (where the permeate from the first stage is fed into a second stack of membranes); the permeate from a single-stage plant is quite adequate for potable purposes although, because of the danger of raw sea water passing through a damaged membrane, it is prudent to chlorinate it.

One major problem encountered was the need to provide an effective filtration system capable of removing suspended solids down to 10 μm in size from the sea water feed. Initially, the filtration fitted to the ships deployed consisted of a washable coarse bag filter followed by a series of disposable cartridge filters giving filtration down to a nominal 10 μm. This proved to be an adequate system of filtration for ships on the open sea, with the filter cartridge being replaced at intervals of between 2 and 4 weeks. However, the situation changed dramatically when the ships moved close inshore at the end of hostilities. In the testing conditions of Port Stanley, one of the ships, T.E.V. *Rangatira*, was replacing the cartridges every 8 hours; the resultant strain on the supply chain was clearly unacceptable. The solution to this problem has been to retrofit the ships with sand filters. In addition, polyelectrolyte is injected into the sea water feed as a coagulant to aid in the removal of the smaller suspended solids. By this means, the interval between cartridge replacements has been increased to between 1 and 2 weeks.

The other major source of problems on the plants was the failure of pipework and components due to excessive vibration. Whilst in some cases this emanated from the ship itself, the more normal source of the vibration was the reciprocating, triplex-plunger HP pump associated with each stack of membranes. These problems have been redressed by paying particular attention to the flow conditions at the HP pump suction to prevent cavitation, the more widespread use of pulsation dampeners and flexible pipework, and by supporting the plants on shock and vibration mounts. Additionally, many of the component materials, particularly in the HP pumps, have been improved.

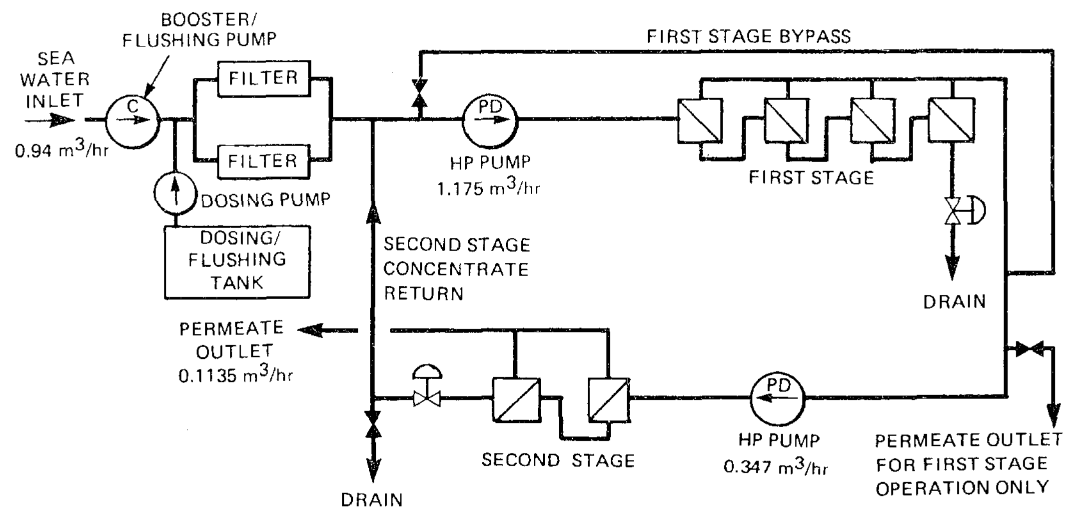

Fig. 4—Type 2400 Reverse Osmosis plant
Symbols as in Fig. 3

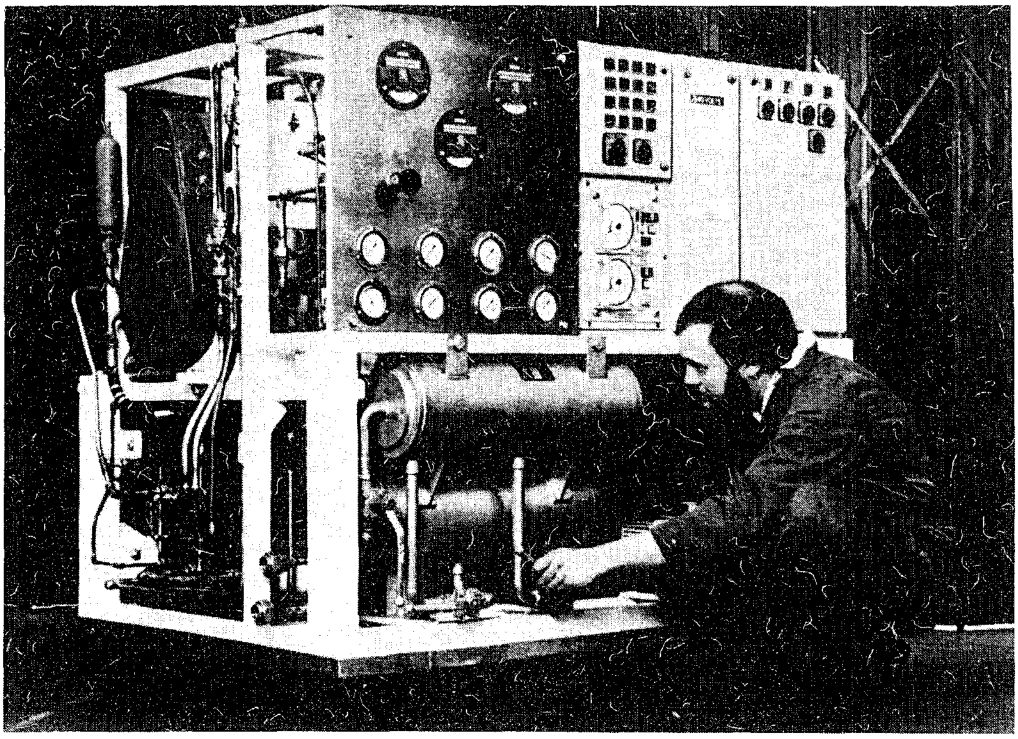

FIG. 5—THE TYPE 2400 REVERSE OSMOSIS PLANT PROTOTYPE

The Type 2400'Upholder' Class R.O. Design

Design work on the reverse osmosis plant for the Type 2400 submarine had progressed to such an extent by the end of the Falklands war that it was not possible radically to alter the design to reflect some of the lessons learned. The plant is a two-stage design with an output of 25 gallons/hr (114 litres/hr) at a temperature of 15°C. A flow diagram of the plant process is in FIG. 4, and a picture of the prototype plant is shown in FIG. 5. Whilst the plant is designed for two-stage operation, each stage is capable of independent operation in the event of the other stage failing. Because of the interdependence of the two stages, the plant is relatively complex. Nevertheless, a compact and satisfactory design has been achieved. The sea water feed is dosed with a sequestrant to prevent any dissolved solids precipitating out in the membranes as the sea water concentrates.

Prototype testing has revealed two main areas of concern:

(*a*) *Noise*. The plant has met its target with respect to structure-borne vibration. However, airborne noise is proving to be a problem and this is the subject of further development. Another possible source of noise, yet to be fully assessed, is fluid-borne noise generated by the pressure drop across the control valve in the concentrate line.

(*b*) *Filtration*. The decision was taken at an early stage in the project to obtain the sea water supply to the plant from one of the boat's compensating tanks. It is now feared that particulate matter will accumulate in this tank and overwhelm the present filtration system of duplex back-flushing filters. An investigation is in hand to find filter elements with an improved ability to retain suspended particles without leading to an increase in the interval between back-flushes.

The Type 23 Frigate R.O. Design

The original reverse osmosis design for the Type 23 allowed for 2 two-stage plants to be installed. This sketch design was then amended to take account of the lessons learned in the South Atlantic, and it now consists of two independent 25 m^3/day single-stage plants with an additional 3 m^3/day plant. The latter plant, configured as a second stage plant, provides water of a higher purity required for gas turbine cleaning, helicopter washing, and diesel generator make-up. The plant process is illustrated in FIG. 6.

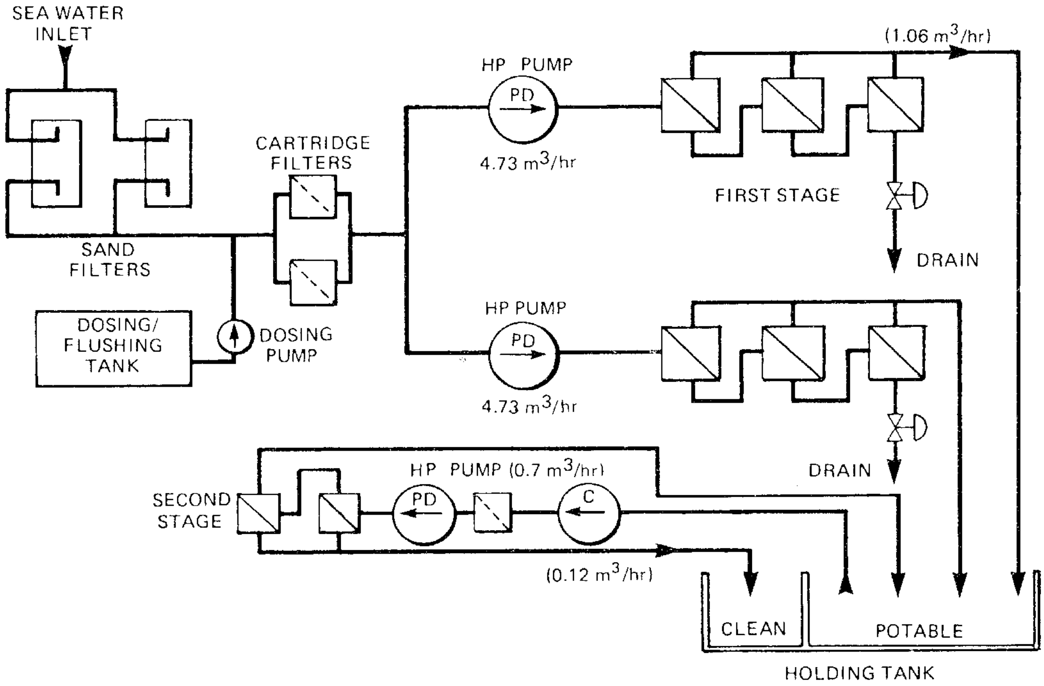

FIG. 6—TYPE 23 REVERSE OSMOSIS PLANT
Symbols as in FIG. 3

Two mixed media sand filters are included in the design to enable the plants to be operated whilst the ship is close inshore, should the need arise; two are specified to permit both first stage plants to be operated sumultaneously, and to enable filtered sea water from one sand filter to back-flush the other when cleaning is required. When this plant is being operated in dirty water the ability to enhance the sand filter performance by dosing the sea water feed with a coagulant is provided, in addition to the dosing with a sequestrant.

The potable water collected in the 8 m^3 holding tank beneath the R.O. plants will be pumped out periodically to the ship's main storage tanks. Because of the inherently higher risk than in conventional distilling plants of contaminated water reaching the storage tanks an electrolytic chorinator will be installed in the transfer line.

In the event of the second stage plant failing, it is possible to reconfigure one of the first stage plants to take a suction from the potable tank and discharge to the clean tank. This operation is not recommended as a matter of course as the lower osmotic pressure of the potable water and different operational recovery ratio can lead to problems with the HP pumps.

Results from the prototype plant (shown installed at ARE, Portland, in FIG. 7) have revealed that the plant is reliable and easy to operate. After

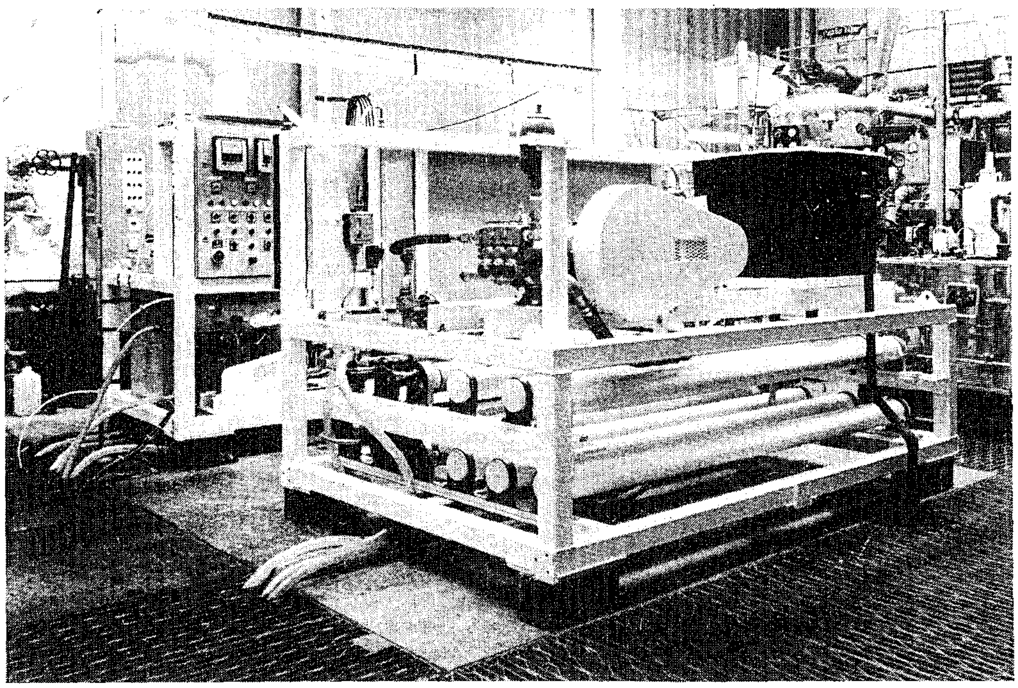

FIG. 7—THE TYPE 23 REVERSE OSMOSIS PLANT PROTOTYPE. THE WHITE SKID IN THE FOREGROUND CONTAINS THE TWO FIRST STAGE PLANTS. THE WHITE SKID IN THE BACKGROUND CONTAINS THE SECOND STAGE PLANT AND THE AUXILIARIES.

1000 hours of operation TDS levels of 170 p.p.m. were being recorded in the first stage permeate, whilst the second stage permeate had TDS levels between 0·7 and 1·8 p.p.m. (approximately half of the TDS consists of chlorides). The principal problem areas are airborne noise emanating from the small centrifugal pumps in the installation, and poor suction conditions at the inlets to the HP pumps which will lead to their premature failure. Both these areas are the subject of further development.

In Conclusion

One result of the Falklands crisis was that R.O. plants were precipitately introduced into the Fleet in larger numbers, and in a less developed state, than would otherwise have been the case. This has meant that, whilst the art of designing R.O. plant installations has rapidly advanced, they have earned a somewhat unjustified reputation for being troublesome. It is confidently expected that the introduction of plants built to MOD standards and developed from the prototype plants under assessment at ARE, Portland, will greatly improve the reputation of R.O. plants for availability and reliability.

Acknowledgements

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