A MODERN APPROACH TO SEA-WATER DISTILLATION

BY

LIEUTENANT-COMMANDER (E) A. M. J. CUMMING, R.N.

Department of National Defence, Ottawa

INTRODUCTION

Present Practice

Considerable research has been directed in recent years to the improvement in performance and the elimination of scale in sea-water distillation plants for naval use. Most of this effort has been directed in studying the chemistry of scale formation, and the retardation or elimination of scale formed on evaporator tubes by the injection of chemical compounds in the sea-water feed.

It having been found that the elimination of scale on the tubes by these methods is impossible, the rated output of the evaporator is now based on :—

(*a*) The output at a conservative tube heat transfer rate comparable to that which exists when the tubes are partially scaled.

(*b*) Increasing the life between descales by retarding the scale formation by using chemical compounds.

(*c*) Reducing the brine density in the shell to $1\frac{1}{2}$ times that of sea-water.

(*d*) Constant output being maintained as the scale increases by the means of orifice control in the steam line to the coils.

Disadvantages

This method of design has the two basic disadvantages that :—

(*a*) The output of the evaporator is assumed to drop as the life between descalings is increased. This involves over-designing the evaporator heating surface so that it will produce its rated output when scaled, with a

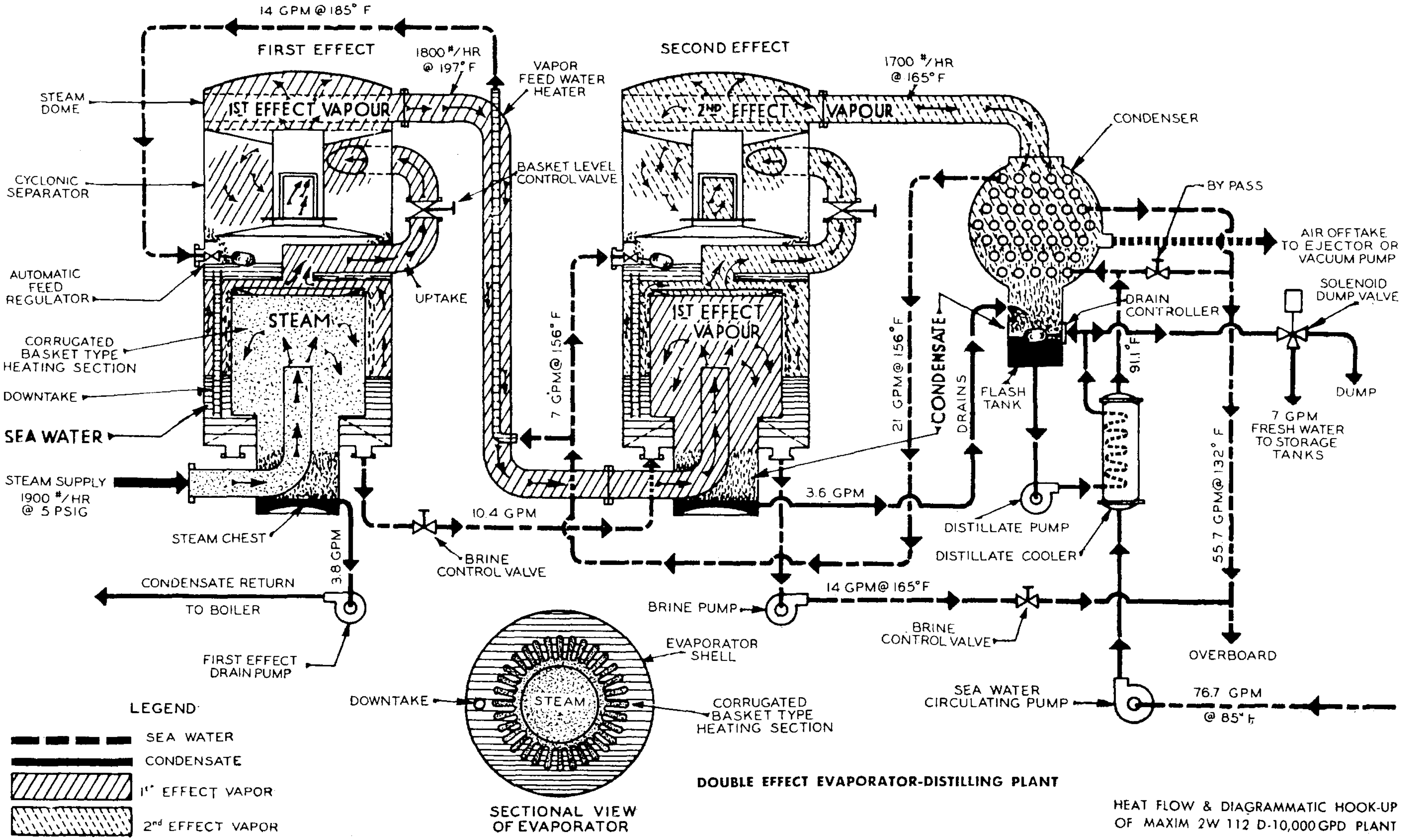
14 GPM @ 185° F
FIRST EFFECT
1800 #/HR @ 197° F
VAPOR FEED WATER HEATER
SECOND EFFECT
1700 #/HR @ 165° F
STEAM DOME
1ST EFFECT VAPOUR
2ND EFFECT VAPOUR
CONDENSER
CYCLONIC SEPARATOR
BASKET LEVEL CONTROL VALVE
BY PASS
AIR OFFTAKE TO EJECTOR OR VACUUM PUMP
AUTOMATIC FEED REGULATOR
UPTAKE
SOLENOID DUMP VALVE
DRAIN CONTROLLER
STEAM
CORRUGATED BASKET TYPE HEATING SECTION
1ST EFFECT VAPOUR
7 GPM @ 156° F
21 GPM @ 156° F
CONDENSATE
DRAINS
FLASH TANK
91.1° F
DOWNTAKE
DUMP
SEA WATER
7 GPM FRESH WATER TO STORAGE TANKS
55.7 GPM @ 132° F
STEAM SUPPLY 1900 #/HR @ 5 PSIG
3.6 GPM
10.4 GPM
STEAM CHEST
DISTILLATE PUMP
DISTILLATE COOLER
BRINE CONTROL VALVE
3.8 GPM
CONDENSATE RETURN TO BOILER
BRINE PUMP
14 GPM @ 165° F
BRINE CONTROL VALVE
OVERBOARD
FIRST EFFECT DRAIN PUMP
EVAPORATOR SHELL
SEA WATER CIRCULATING PUMP
76.7 GPM @ 85° F
LEGEND
DOWNTAKE
STEAM
CORRUGATED BASKET TYPE HEATING SECTION
SEA WATER
CONDENSATE
1st EFFECT VAPOR
2nd EFFECT VAPOR
SECTIONAL VIEW OF EVAPORATOR
DOUBLE EFFECT EVAPORATOR-DISTILLING PLANT
HEAT FLOW & DIAGRAMMATIC HOOK-UP OF MAXIM 2W 112 D-10,000 GPD PLANT

FIG. 1

consequent increase in weight and space over that surface, which would otherwise be necessary if the clean tube rating could continually be maintained. A loss in output over the clean tube rating of about 25 per cent. is accepted.

(*b*) The complication of chemical injection into the salt-water feed has to be accepted if the life is not to be adversely affected.

Design for Maximum Performance

Heat Transfer. To obtain maximum output with minimum weight and space a higher heat transfer in the evaporator tubes is necessary and these must be kept as free from scale as possible if the output is not to fall off.

Vapour Hoods. If the heat transfer is increased appreciably, present vapour hoods are inadequate to meet increased rates of vapour velocity, therefore if the former premise of a constant higher heat transfer rate can be implemented it follows that a radically new design of vapour hood is necessary to prevent carry-over.

MAXIM SILENCER EVAPORATORS

The Maxim Silencer Company, Limited, Hartford, Connecticut, U.S.A., has produced a unit which embodies these basic design principles as well as incorporating the latest ideas on ease of operation. A typical arrangement for a 10,000 U.S. g.p.d. unit is shown in FIG. 1.

Design Characteristics

Basic design characteristics are achieved by :—

(*a*) Substituting the conventional coils or tube nest with a vertical-corrugated monel basket type heating element.

(*b*) Using a cyclonic type separator instead of the conventional baffle type vapour hood. (FIGS. 2 and 3.)

Heat Transfer. Because of the descaling characteristics of the monel basket heating element, the heat transfer can be raised from the conventional dirty tube rating of 400 B.Th.U/Hr/sq. ft/°F. to 550 B.Th.U/Hr/sq. ft/°F.

Cyclonic Separator. The cyclonic separator produces adequate separation of the entrained solid particles from the vapour and it is interesting to note that a velocity of about 150 ft. per second is experienced in the pipe leading from the shell to the cyclonic separator through the basket level control valve. Conventional hoods at a shell pressure of 5 lb/sq. in. gauge deal with velocities of the order of 5 ft. per second.

Closed Exhaust Steam. The high heat transfer coefficient used and the insensitivity of the plant enables closed exhaust steam to be used in the basket heating element. For a 10,000 U.S. g.p.d. double effect plant with a brine density of 15°, 1·8 lb of fresh water is made for every pound of steam used in the first effect.

Scaling Characteristics

Blowing Down. Scale is cracked off during the conventional blowing down operation by the flexing of the basket fingers. This flexure is such that normally all the scale formed is cracked off except for a little remaining at the base of the fingers.

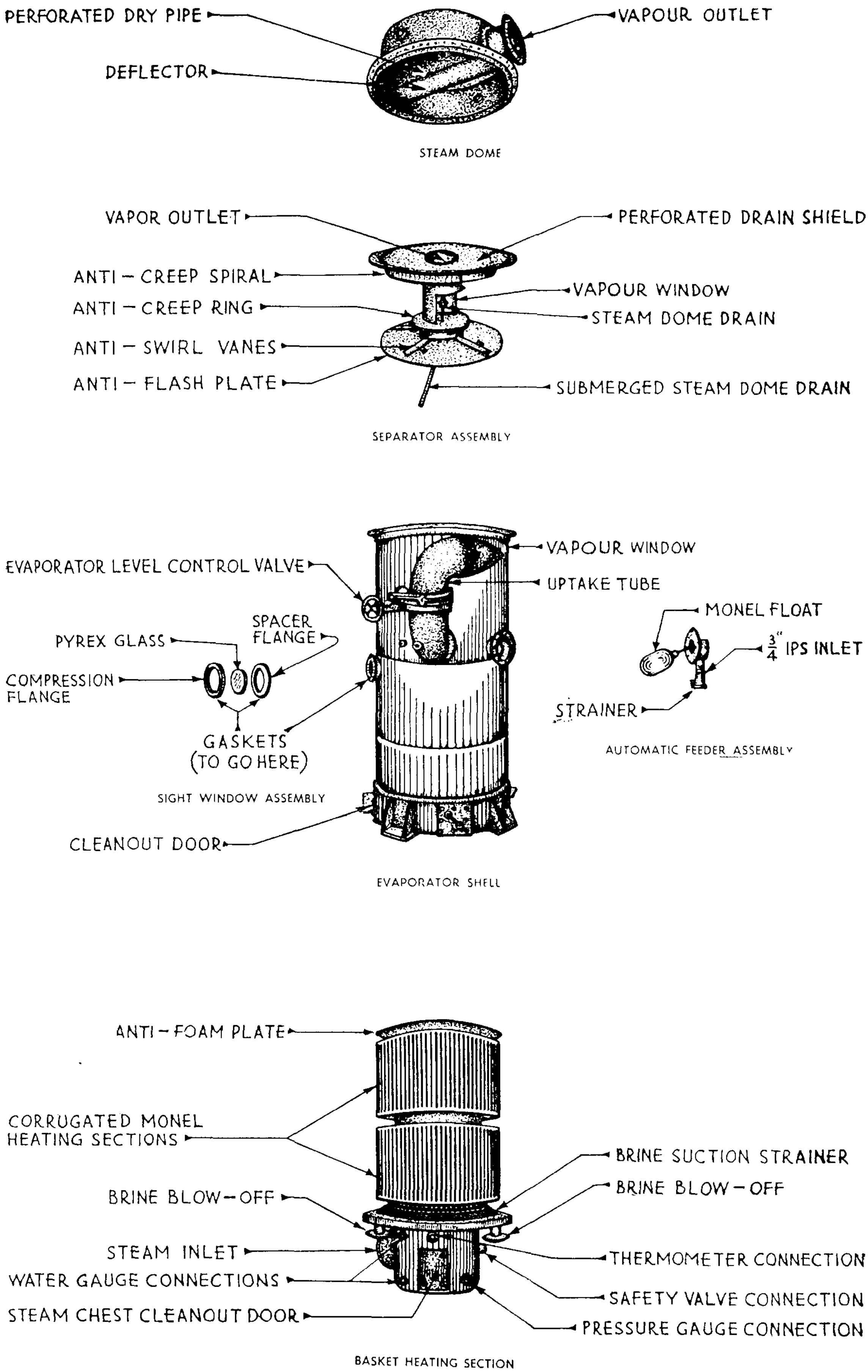

FIG. 2—EXPLODED VIEW OF W112D EVAPORATOR

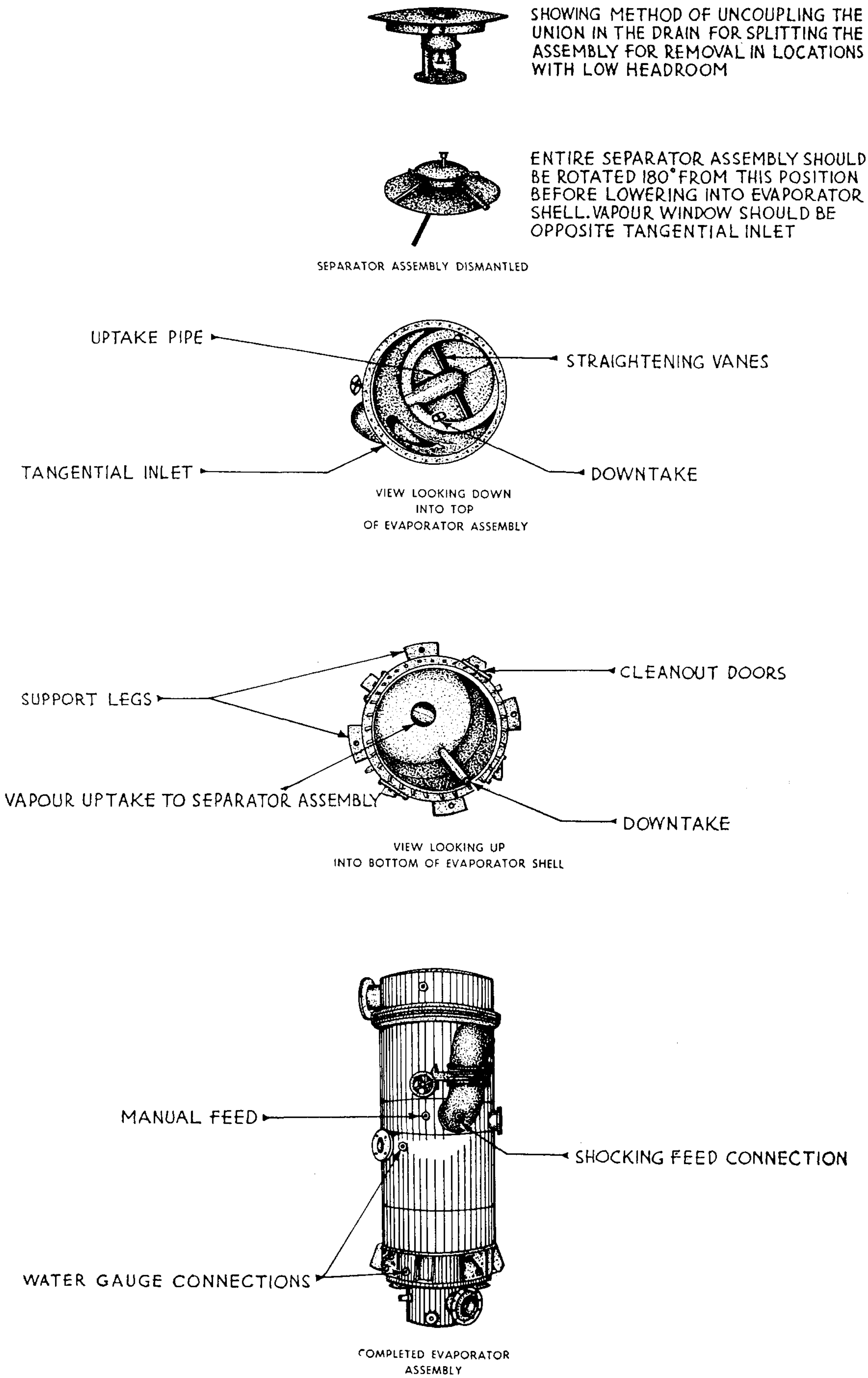

FIG. 3—EXPLODED VIEW OF W112D EVAPORATOR

Scale Retardation. Retardation of scale formation is achieved by the now normal practice of reducing the density of the brine in the shell to 15°, and by the salt-water feed passing into the cyclonic separator where it is heated by the vapour. This heating drives off the entrained carbon dioxide before the salt-water feed enters the down-takes to the evaporator basket section, thus tending to eliminate the formation of calcium carbonate scale. The basket heating section promotes surface velocities of the order of 8 to 12 ft. per second which reduces the formation of scale, by a washing action, particularly of calcium sulphate whose precipitation is however already retarded by reducing the brine density to 15°.

Results. Service experience has shown that after 2,000 hours operation the average accumulated scale thickness formed was 1/32 in. and the maximum 50/1,000 in. This scale was eighty per cent. magnesium hydroxide, which would indicate that the carbon dioxide liberation is good and that calcium sulphate is not forming. It also demonstrates the effectiveness of the blowing down operation.

Water Level Control

Water level regulation is achieved by :—

(*a*) A float control valve.

(*b*) The vapour take-off valve, or basket level control valve, to the cyclonic separator. Closure of this valve produces higher rates of vapour flow with consequent pressure drop through the valve. The pressure is therefore increased in the evaporating section, and will support a liquid level through the downtakes in the separating section equal to the pressure differential. Since the float operated valve will maintain a constant upper level in the cyclonic separating section, anything that is done to increase the pressure differential will effectively lower the level of water on the evaporating section. Lowering the water level will decrease the pressure differential thereby causing the water level to rise, and increasing the output. The system therefore finds its own level and produces water at a constant rate. As the basket becomes scaled, the water level rises due to less vapour being generated and contacts more heating surface thus the output of the evaporator remains substantially constant.

Density Control

A refinement is introduced in the control of the brine density in the evaporator shell. Flow-meters are installed in the sea-water feed line to the first effect and in the fresh water discharge line. As long as the flow-meter on the sea-water line reads twice that of the fresh water discharge line the density in the first effect will be maintained at 15°. This method allows a continuous check on the density and eliminates the need of taking readings at frequent intervals with a hydrometer.

Life

The evaporator was designed originally so that it would produce water at a constant output for a period of 75 hours without blowing down. However, it would appear that this period can be increased, as in service it has been found that scale has not formed at the rate expected. Blowing down, as already described removes the scale and renews the life of the unit. Operating experience is being obtained as to how long this process can be repeated before excessive scaling occurs on the heating basket element. From operations in commercial and naval practice the descaling period as at present laid down is 4,000 hours but it would appear that yearly descaling would be adequate. This period may well be prolonged. Descaling is a relatively easy operation ; the basket is heated by means of a torch—the scale drops off.

Materials

All Royal Canadian Navy evaporators to this design will have shells and baskets manufactured in monel to reduce weight and increase resistance to corrosion. Aluminium bronze shells are however being introduced for commercial practice, the baskets being retained in monel. Particular care has been taken to select corrosion resistant fittings and associated equipment. The only complicated part to manufacture is the basket heating element. The ends of the corrugated fingers are welded, but since satisfactory welding techniques have been developed, no basket failures have been experienced.

ADOPTION BY ROYAL CANADIAN NAVY

The Maxim evaporator in the 10,000 U.S. g.p.d. double effect size was adopted in principle by the Royal Canadian Navy about two years ago, as it became obvious that to obtain adequate fresh water capacity without requiring larger machinery spaces, the conventional submerged tube type evaporators would not meet requirements. The Maxim evaporator was the only unit then designed which would meet those requirements, and was in keeping with the general concept used in the design of modern propulsive machinery, that is reliability, low weight and space requirements, and ease of operation.

THE FUTURE

The Maxim type evaporator is designed on conservative heat transfer rates as there is, as yet, insufficient information to rate the units higher and ensure that output does not fall off. As more information is collected, and from present experience with units in service (all produce more than their rated outputs at 5 lb/sq. in. gauge after long periods in service) it would seem that it may be possible to increase the heat transfer rates and reduce the present sizes of the units for any given rated output.

HEAT BALANCE FOR MAXIM 10,000 U.S. g.p.d. PLANT

Based on flows and temperatures shown in Fig. 1

1. Heat required in first effect per hour :—

Sea Feed	7,000 lb (197–185)	=	84,000
Vapour	1,800 lb (979·7)	=	1,763,000
			1,847,000 B.Th.U/hr

2. Heat Transfer in first effect, surface area 112 sq. ft. :—

$$U = \frac{1,847,000}{112\ (227-197)} = 553 \text{ B.Th.U/sq. ft/hr/°F.}$$

3. Steam required at 5 lb/sq. in. gauge :—

$$\frac{1,847,000}{961} = 1,920 \text{ lb/hr}$$

4. Heat required in second effect :—

Feed inlet = 156°F.

Sea Feed	3,500 (165−156)	=	31,500
Vapour	1,700 (999)	=	1,698,000
			1,729,500 B.Th.U/hr

5. Heat available in second effect.

(*a*) Heat lost in vapour feed heater/lb :—

$$\frac{7,000\ (185-156)}{1,800} = 112{\cdot}6 \text{ B.Th.U/lb}$$

Heat available in vapour/lb :—

1,144·6−112·6 = 1,032 B.Th.U/lb

(*b*) Heat available :—

1,800 (1,032−165)	=	1,561,000
5,200 (197−165)	=	166,400
		1,727,400 B.Th.U/lb

6. Service Heat Transfer in second effect :—

$$U = \frac{1,729,500}{112 \times (197-165)} = 480$$

7. Heat rejected to condenser :—

1,700 (999)	=	1,698,000
1,800 (197−165)	=	57,600
	Total	1,755,600 B.Th.U/hr

8. Heat in feed :—

10,500 (156−132) = 252,000 B.Th.U/hr

9. Heat absorbed by cooling water :—

1,755,600−252,000 = 1,503,600 B.Th.U/hr

10. Cooling water required :—

$$\frac{1,503,600-}{132-91{\cdot}1} = 37,000 \text{ lb/hr} = 76{\cdot}7 \text{ U.S. g.p.m.}$$