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Modern Marine Closed Feed Systems*

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The operating conditions of steam boilers in British ships have steadily increased over the past thirty years. About 1920, average operating conditions would be 200-250lb. per sq. in. gauge with total steam temperature from 400-500 deg. F. From 1930-40 the maximum conditions would be 300-400lb. per sq. in. gauge and 650-750 deg. F. total temperature. Present day advanced steam conditions are of the order of 500-750lb. per sq. in. gauge with total temperatures of 750-850 deg. F.

In this advance in steam conditions we have gone forward more cautiously than either American or German marine engineers. From about 1933-45, Germany had had a number of marine boiler installations operating at from 800-3,200lb. per sq. in. gauge and total temperatures of 750-900 deg. F. In America, about the same period, steam conditions could be taken as ranging from 450-1,450lb. per sq. in. gauge and 750-950 deg. F. Fig. 1 indicates the general trend of advancing steam conditions from 1920-1948 in these three countries.

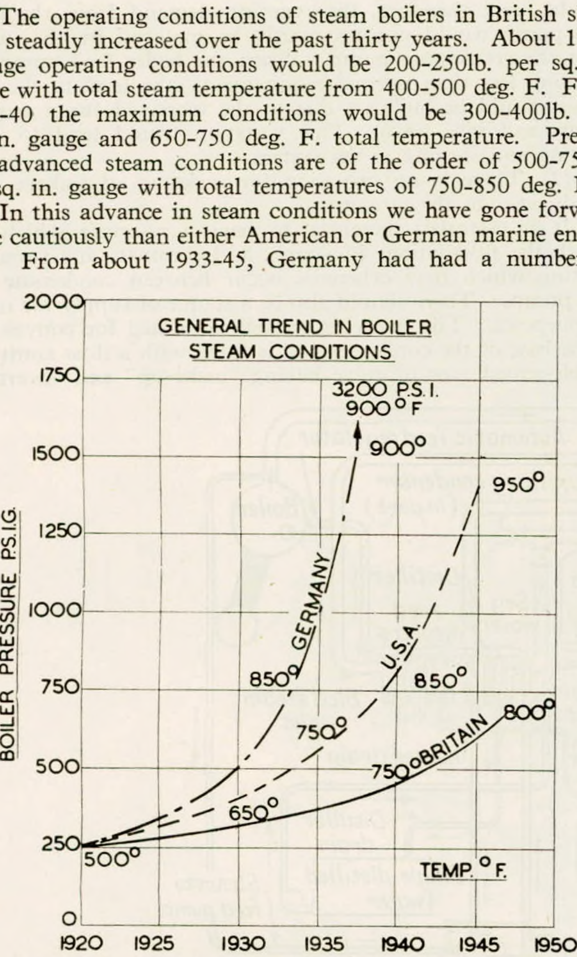

FIG. 1—*General trend in boiler steam conditions for marine service*

In both America and Germany, as the steam conditions increased so also did their operational troubles due to corrosion difficulties. Corrosion in boilers is largely due to dissolved oxygen in the feed water and increases very rapidly with rise in boiler tube operating temperature. When the oxygen content of the feed water is high, pitting and perforation of the tubes and drum take place, with consequent outage of the boiler. It will be seen, therefore, that the higher the boiler operating conditions, the lower should be the oxygen content of the feed water to safeguard the boiler tubes and drum. Optimum deaeration of the feed is therefore of extreme importance for maximum availability.

Feed water which has been deaerated will, if permitted, absorb gases much more rapidly than non-deaerated water. It is important, therefore, that the feed circuit should be completely airtight, and strict attention should be paid to sealing of glands operating under sub-atmospheric conditions and return of drains to points in the system—no oven pigs' ears, collecting tanks, etc., to be used.

Considerable research work was carried out in America and Germany on corrosion problems prior to and during the recent world war. In each case the marine engineers of these two countries arrived at an identical solution to their corrosion troubles, the answer being to alter their open or semi-open feed water systems to the closed feed type.

The closed feed water system has been successfully fitted in most of the principal British steamships over the last quarter of a century, and credit for its main development should be given to a Scottish engineering firm, G. and J. Weir, Ltd., who have been investigating corrosion difficulties in boilers, etc., prior to and since the beginning of this century. One of their early suggestions towards overcoming corrosion was to deaerate all make-up feed water before introducing it into the feed circuit, so removing dissolved oxygen, carbon dioxide and other active corrosive gases from the make-up feed. Primarily, their object was to provide for the complete exclusion of air from contact with the feed water throughout the feed circuit, thus preventing absorption of air and consequent contamination of

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the feed. Events have since shown that this is the one certain method of ensuring corrosion-free operation of steam generating plants.

The closed feed system, therefore, is fundamentally concerned with preventing air from coming into contact with the feed water by using a closed circuit, thus preventing any absorption of air by the feed water, and so eliminating corrosion from the boiler and its associated equipment. In addition, it provides a flexible feed system which under all steaming conditions, is automatic in operation.

Corrosion in boilers can be attributed to one or more of the following factors:—

(*a*) Dissolved oxygen and carbon dioxide in the feed water;
(*b*) acidic condition of the feed water;
(*c*) electro-mechanical or galvanic action due to (*a*) and (*b*).

Dissolved oxygen is the principal militant factor in corrosion, and its reduction to below 0·02 cc. per litre in the feed system has a pronounced effect in reducing corrosion problems, and in most cases completely preventing them. Carbon dioxide is generally present in such minute quantities that it can be disregarded.

Treatment or conditioning of the feed water to reach a *p*H value of 9·0-10·0 in the boiler will nullify acidic conditions of the feed water. Briefly, the *p*H value is a measure of the acidic or alkalinic condition of the feed. If the value is greater than 7·0 the water is alkalinic, whilst for values under 7·0 it would be acidic.

Electro-mechanical or galvanic corrosion can be considerably reduced by:—

(*i*) removing the dissolved oxygen;
(*ii*) treating the feed water; and
(*iii*) where metals have to be in contact, electrolytically and mechanically, ensuring that they are close to each other on the galvanic scale. This scale lists the metals in common use in a particular grouped sequence. Those metals which are close in potential are listed together and, where two dissimilar metals are used, they should be chosen where practicable from the same group or relatively close groups to ensure having the minimum possible potential difference between them, so reducing the danger of galvanic corrosion.

It will be obvious from the foregoing that dissolved oxygen is the most important contributing factor to corrosion in the boiler, main engines, ancillary equipment and associated feed piping. Removal of dissolved gases and neutralization of salts, plus satisfactory alkalinity of the feed water, should be aimed at to ensure reduction of electro-mechanical corrosion to the minimum obtainable under operating conditions.

The basic closed feed system would comprise a condensate extraction pump, drawing from the condenser of the prime mover and delivering into the suction of the boiler feed pump, which would then supply feed water to the boiler. It will be clear, however, that this system would be inoperable for two reasons:—

(1) The considerable variation in boiler storage capacity under different steaming conditions creates wide fluctuations in the condenser level. With a boiler under steady steaming conditions, the observed gauge glass water level is approximately constant. There is a definite proportion of steam to water under the water level and, should the main engines now require increased steam quantity, the percentage of steam below the observed water level increases, raising the indicated level in the boiler drum. The boiler feed pump is controlled by the boiler water level and reduces its output as the level in the boiler increases and *vice versa.* With the temporary rise in level due to the increased steam requirements of the main engines, the output of the pump is reduced. Similarly, if the steam requirements of the main engines are reduced, the level in the boiler subsides and the pump increases its output. It will be seen, therefore, that varying demand from the boiler feed pump would not necessarily be matched by the output from the condensate pump. When the boiler feed pump was handling less than normal requirements, the level in the condenser would be built up due to the increased steam requirements, and *vice versa.* This situation would tend to cause hunting and surging in the system.

(2) There is no provision for make-up of leakage from glands, etc., in the circuit.

It is essential, therefore, to have a reservoir which can absorb the fluctuations in supply and eliminate any surges or hunting which may otherwise occur between condensate and feed pumps. There should also be a source of supply for make-up purposes. The reservoir or well is located for convenience in the base of the condenser and is fitted with a float controlled double-seated type of valve having "make-up" and "overflow"

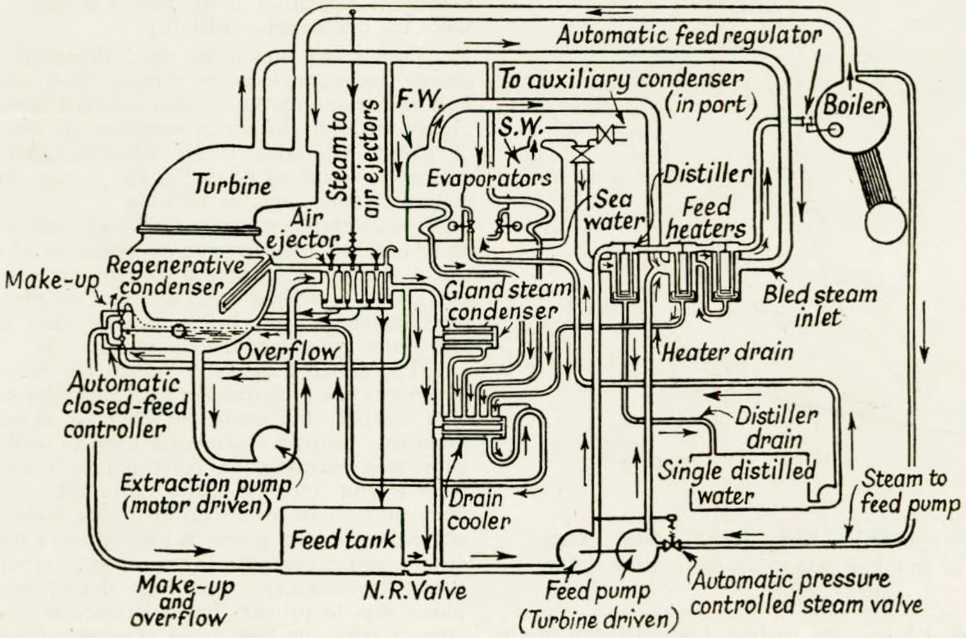


FIG. 2—*Modern closed-feed system*

connexions. This valve maintains the required level in the condenser, passing condensate to a feed tank or drawing from the feed tank as occasion demands. The water from the feed tank, which is, of course, make-up water, is therefore deaerated in the condenser before being introduced into the feed system.

The following list gives the units and the order in which they are introduced into the feed circuit between the condenser condensate outlet and the boiler feed water inlet:—

(*a*) Closed feed controller;
(*b*) condensate extraction pump;
(*c*) steam jet air ejector and condenser;
(*d*) glands condenser;
(*e*) recirculating valve;
(*f*) drain cooler;
(*g*) l.p. heater;
(*h*) boiler feed pump;
(*j*) h.p. heater or heaters;
(*k*) boiler feed regulator.

The system may also incorporate feed filters, deaerating plant, evaporating plant, and perhaps an auxiliary steam generator.

Fig. 2 shows a typical diagrammatic arrangement of a closed feed system and a brief description of each of the units involved follows:—

Main Condenser.

To ensure optimum deaeration of the feed water, it is essential that the condenser be of the regenerative type so that the dissolved oxygen content in the condensate at the outlet from the condenser is not greater than 0·02 cc. per litre. This figure is readily obtained with a well-designed condenser having suitable steam lanes and nil partial air pressure. Fig. 3 illustrates a modern form of regenerative condenser, showing first flow circulating water tube nest (A); second flow circulating water tube nest (B); converging steam centre lane (C); baffle plates (D); air suction connexion (E); condensate outlet branch (F); circulating water inlet connexion (G); facing for closed feed controller (H); circulating water outlet connexion (J).

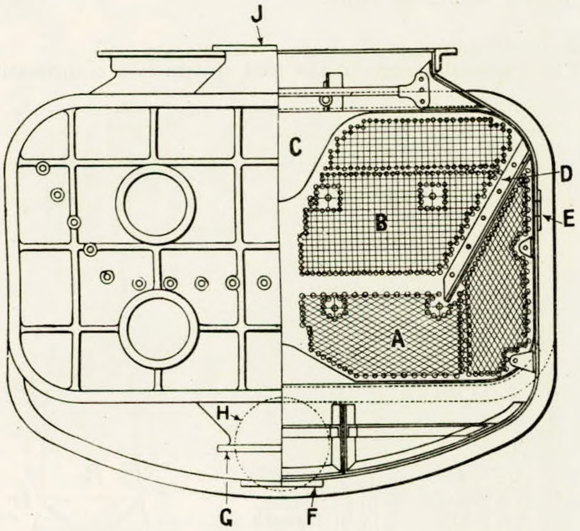


FIG. 3—*Modern form of regenerative condenser*

The word "regenerative" signifies that the condenser, after condensing a portion of the incoming exhaust steam, reheats it with the remaining exhaust steam in such a way that the condensate temperature at the outlet from the condenser is equal to or within 2 deg. F. of the saturation temperature corresponding to the exhaust pressure at the eduction. This function is carried out by providing suitably arranged steam lanes which permit a proportion of the exhaust steam to flow to the base of the condenser and reheat the drops of condensate which may have been undercooled during their passage through the tube bundle. Baffles are formed in the sides of the condenser and operate as air coolers. The reason for cooling the air before removing it is to increase its density so that a given mass occupies a smaller volume and it is therefore more easily handled by the air ejectors. Generally, the air suction belt is arranged two or three rows of tubes down from the junction of the baffle and condenser shell, to ensure that the cooled air does not come into contact with the relatively hot baffle plate.

This regenerative effect has two important features:—

(1) Deaeration;
(2) thermal efficiency.

Regarding the first, it is known from Dalton's "Law of Partial Pressures", that in a vessel containing a mixture of a number of gases or vapours, each individual gas exerts its own partial pressure as though it were the only gas in the vessel and the summation of the individual partial pressures gives the total pressure in the vessel. In the case of a condenser, the mixture is made up of a condensable vapour and air. Since the mixture is saturated, its temperature determines the vapour temperature and therefore its pressure. The partial pressure of the air is, therefore, the total pressure in the condenser as measured by a gauge, minus the pressure equivalent to the saturated temperature of the vapour found from the steam tables. As the condensate temperature is increased by regeneration, the water vapour pressure also increases, causing a corresponding reduction in the partial air pressure which reaches nil at the condensate outlet, the condensate then being free of air.

Secondly, there is a considerable saving in heat, since, if the condensate was undercooled instead of regenerated, there would be a loss of heat from the feed to the circulating water in the system, and it would be necessary to replace this heat loss in the feed water from an exhaust or bled steam supply if the feed inlet temperature to the boiler is to be maintained.

Closed Feed Controller

The closed feed control valve, as shown in Fig. 4, is fitted in the base of the condenser and maintains the required water level therein. The controller comprises two valves machined integrally on the same spindle. The "make-up", or supplementary, valve which is in the topmost position, permits water to pass from the feed tank to the main condenser when the float is in the lower position. The smaller valve or overflow valve allows water to be discharged out of the system by the condensate pump to the feed tank when the level in the condenser is high. In the travel of the valve there is a lazy position which permits minor fluctuations in the condenser level to take place without continuous movement of the valve.

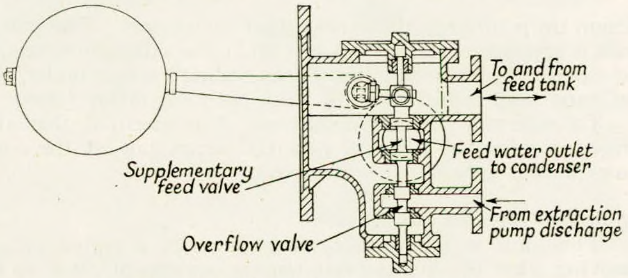
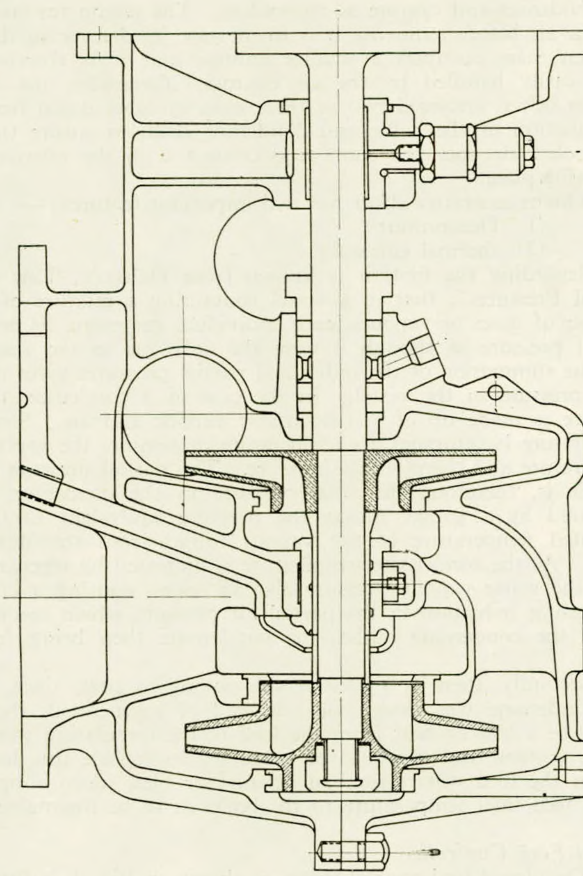


FIG. 4—*Closed feed control valve*

Condenser Extraction Pump

The condensate is withdrawn from the condenser, generally by means of a vertical two-stage centrifugal pump. A typical pump is shown in Fig. 5.

The first stage impeller is designed normally to raise the pressure of the condensate in the system from the vacuum condition obtaining in the condenser up to atmospheric pressure. The second stage impeller gives the necessary head to overcome the various losses between the extraction pump discharge and the feed pump suction, these losses comprising pipe friction and



SECTIONAL ARRANGEMENT OF CONDENSATE EXTRACTION PUMP

FIG. 5

friction drop through the various heat exchangers. The pump speed is approximately 1,000-1,400 r.p.m. for satisfactory design and operation when handling "near-boiling" water under the low static head available in the ship, normally about 3 feet.

To minimize heeling conditions it is essential that the extraction pump be fitted as near the centre line of the condenser as the installation will permit.

Steam Jet Operated Air Ejector

This unit is the method now generally accepted of air removing (that is, vacuum maintaining equipment), due to its simplicity, compactness, smallness and absence of moving parts. Fig. 6 shows a typical air ejector and condenser.

The general principle of the steam operated air ejector is to compress the air in a number of stages from condenser vacuum to atmospheric pressure. Each stage follows the same principle and, depending on the vacuum to be maintained in the main condenser, the ejector would be of the one, two, or three stage design, each stage comprising a steam nozzle discharging into a diffuser.

The potential energy of the supply steam is transformed into kinetic energy in a convergent divergent nozzle. The steam is approximately 5 per cent underexpanded and leaves the nozzle with an exit velocity of from 3,500 to 4,000ft. per sec. The steam jet entrains the air by friction and the combined mass of steam and air is discharged into a diffuser. In this diffuser, part of the kinetic energy is reconverted into pressure energy so that the air is discharged at a pressure higher than the ejector suction pressure.

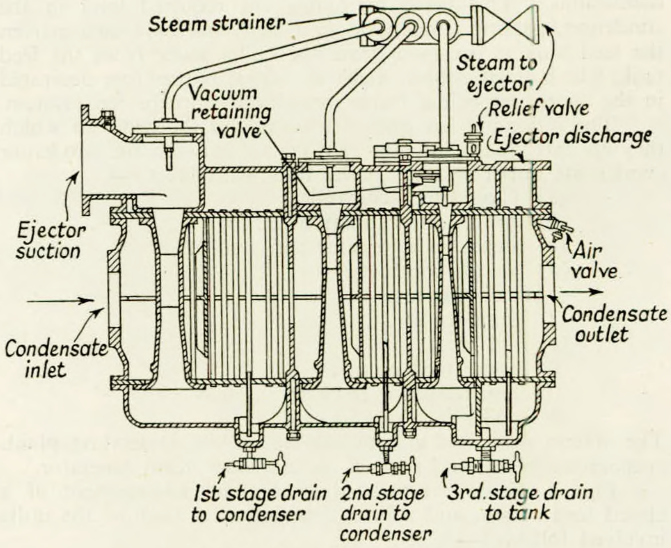


FIG. 6—*Three-stage air ejector*

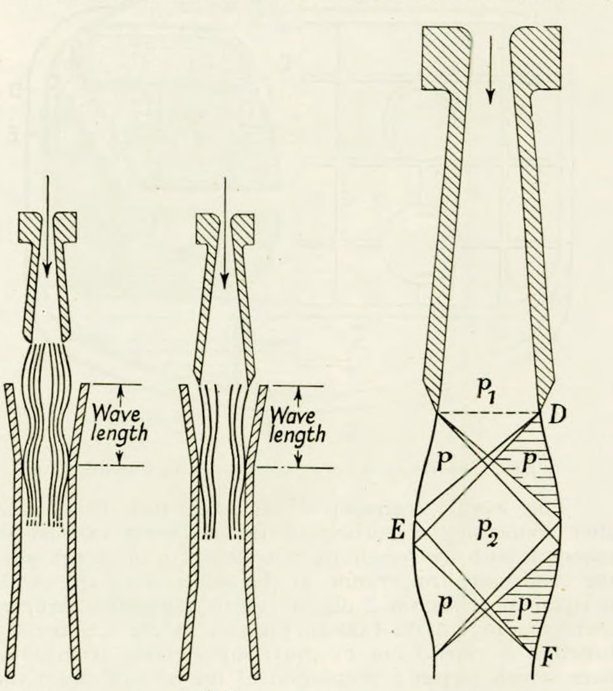
The mixture of air and vapour is cooled after each stage to reduce the amount of air to be handled by the successive stages. The vapour entrained with the air and the operating steam is condensed by condensate flowing through the ejector condenser on the outside of the cooling tubes. The air ejector shown has its first and second stage drains generally taken to the condenser and the third stage drain to the feed tank.

The relative position of nozzle exit to diffuser inlet is important and is arranged to give a series of waves in the diffuser, as indicated in Fig. 7, which entrain the air and finally discharge it to the atmosphere.

A single stage unit will maintain a vacuum of up to 26″ Hg., a two stage up to 29″ Hg., and over this a three stage ejector would be fitted.

Glands Condenser

This particular item of the feed system is a comparatively



(*a*) (*b*) (*c*)

FIG. 7—*Wave formation of the operating steam in air ejectors*

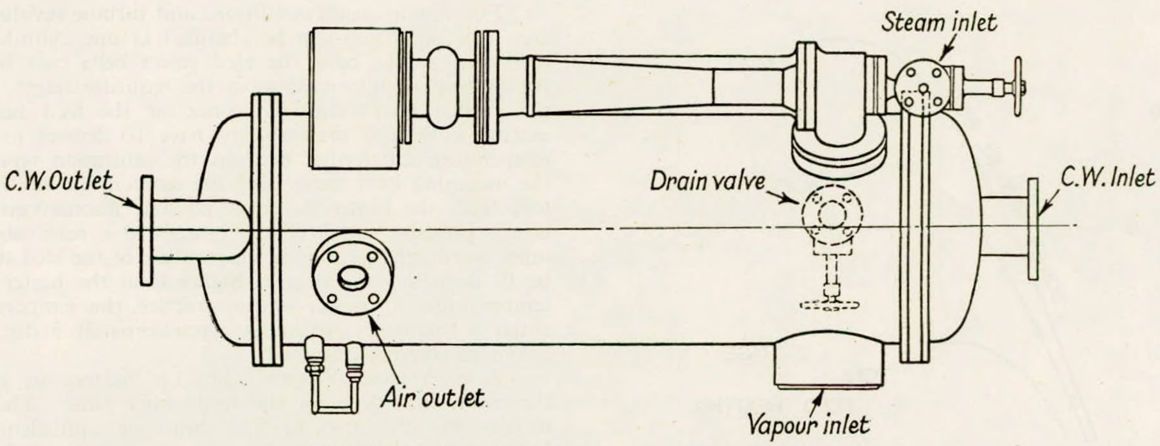


FIG. 8—*Outline arrangement of glands condenser*

recent innovation. Its prime purpose is to maintain a sub-atmospheric condition in the gland pockets of the main turbine glands. It is fitted with a small steam-operated single stage air ejector which removes the air and vapour from the gland pockets and thereby increases the habitability factor of the engine room. Prior to the fitting of this equipment the vapour from the main engine glands condensed, generally overhead, and created a shower of condensate which was annoying to the engineroom personnel.

Fig. 8 shows an outline arrangement of a glands condenser. The air and vapour mixture is inhaled at the inlet to the gland condenser. The vapour is condensed and the air inhaled by the steam jet air ejector discharged into the ejector condenser. The nozzle steam is condensed in the ejector condenser and the air is released through a vent pipe. The gland vapour and the ejector steam are condensed in separate compartments which are circulated in parallel by the relatively cool condensate. The drain from the ejector condenser is taken through a looped sealing pipe to overcome the difference in pressure in the two compartments.

Recirculating Valve

This valve is used during starting-up, manœuvring or shutting-down operations. Its function is to ensure the circulation of condensate through the steam jet air ejector and gland condenser for the purpose of condensing the operating steam.

Drain Cooler

As its name indicates, this heat exchanger is responsible for the cooling of the hot drains from the various units in the closed feed system to a temperature suitable for introducing these drains into the main feed tank without overheating it. The drain cooler as shown in Fig. 9 is circulated by the feed condensate, the temperature of which it increases in the order of 10 deg. F., depending on the operating conditions. To obtain good heat transmission, as this is a "fluid to fluid" heat exchanger, the hot drains flow through a well baffled path in the shell before entering the feed tank or condenser as the case may be.

Feed Water Heaters

The general line of demarcation for feed heaters in the closed feed system is whether they are fitted on the suction or discharge of the boiler feed pump, all heaters fitted before the boiler feed pump generally being termed low pressure heaters and those fitted after it, high pressure heaters. The feed heating system is a very important factor in the design, operation and heat economy of ships' machinery. Considerable research has been carried out to determine the most economic final feed temperature it is advisable to carry for any given boiler pressure. There is an optimum final feed temperature for each set of conditions and it is necessary, therefore, to make use of calculated estimating curves to enable determination of the economic final feed temperature to be made. This should be done in conjunction with the boiler designer, particularly if economizers and/or air preheaters are fitted, to obtain the best thermal efficiency. Fig. 10 gives typical curves.

Generally speaking, in the feed heating portion of the closed feed system it is usual to take any auxiliary exhaust steam to the low pressure heater, and cascade the high pressure heater drains into it also. In the case of high pressure heaters the heating steam is bled from the main engines at suitable pressures necessary for the final feed temperature, previously determined, to be obtained.

A typical three-cylinder turbine condition curve plotted on a Mollier heat-entropy chart is shown in Fig. 11. P1, T1 and H1 indicate the pressure, temperature and total heat of the steam before the nozzle control valves. P2, T2 and H1 represent the steam conditions in the steam belt before the nozzle inlets. The isothermal pressure drop from P1 to P2 is purely a throttling condition, the total heat remaining constant except for any slight radiation losses.

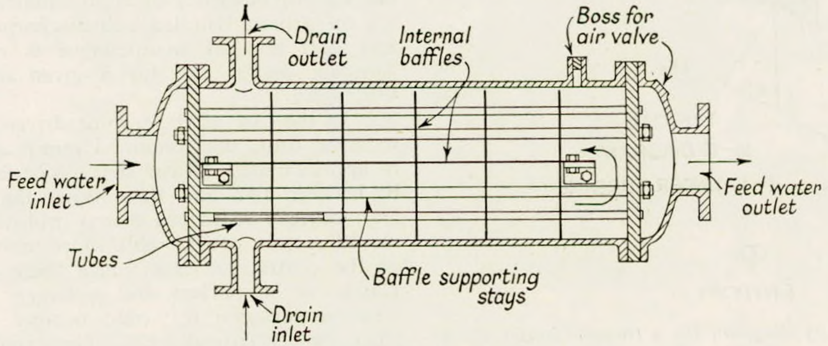


FIG. 9—*Drain cooler*

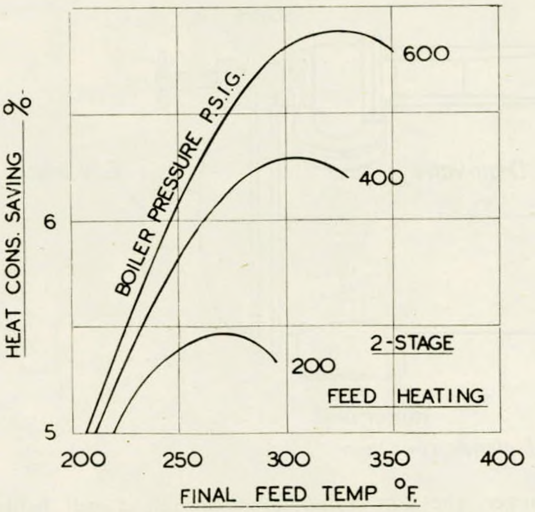


FIG. 10—*Typical curves for determination of feed temperature*

In the h.p. turbine cylinder, the steam expands adiabatically from P2 to P3, but due to various internal losses such as nozzle, disc and blade friction, windage, etc., the steam is reheated to the condition P3 : T3 : H3, giving the exhaust condition at the h.p. cylinder and the inlet condition at the i.p. cylinder.

As in the case of the h.p. cylinder, the steam again expands adiabatically in the i.p. cylinder and is reheated to condition P4 : T4 : H4, which is the exhaust condition for the i.p. and the inlet condition for the l.p. cylinders. The steam is further expanded in the l.p. cylinder, reheated due to the various internal friction losses as previously mentioned, and the final exhaust steam condition at the l.p. cylinder outlet and the condenser inlet would be P5 : H5.

For two-stage feed heating, it would be simpler to take the bled steam from the interconnecting pipes between the h.p. and i.p. cylinders, and the i.p. and l.p. cylinders, as this enables simple castings to be made of the turbine casings since no bled steam belts would be required. P3 : T3 : H3 and P4 : T4 : H4 would then be the steam conditions at the h.p. and i.p. heater inlets respectively.

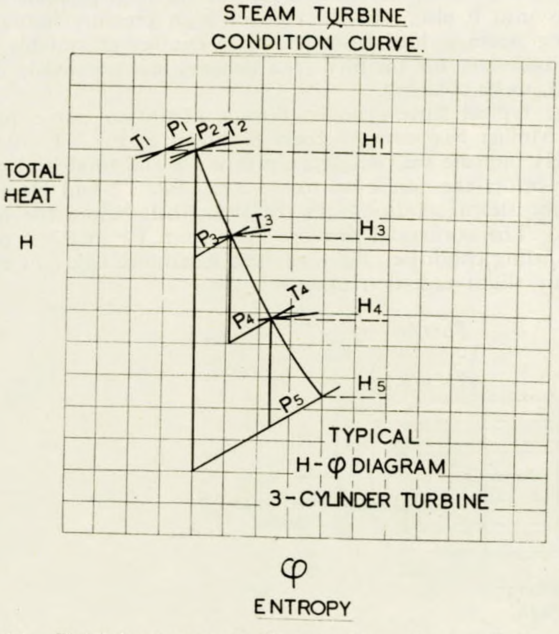


FIG. 11—*Total heat-entropy diagram for a three-cylinder steam turbine*

For certain steam conditions and turbine revolutions, however, full expansion can be obtained in one cylinder and it is then essential to have the bled steam belts cast integrally in the turbine cylinder casings at the requisite stages, which give the correct bled steam pressures for the feed heaters. For marine work it is preferable to have 10 degrees to 15 degrees temperature differential between the saturation temperature of the incoming bled steam and the temperature of the outgoing feed from the heater, to cover possible fluctuations in turbine nozzle pressure and keep the heaters to a reasonable size. In other words, the saturation temperature of the bled steam should be 10 degrees to 15 degrees higher than the heater outlet feed temperature. In power station practice, this temperature differential is frequently reduced to approximately 5 deg. F. to give optimum thermal efficiency.

Low Pressure Heaters. The l.p. heaters are generally of the multi-pass type on the feed water side. The tubes are usually manufactured in S.D. brass or equivalent and have Crane type packing, similar to condenser tube fittings, on the tube ends. The shell is fabricated in mild steel with scantlings to meet the requisite exhaust or bled steam conditions. The water side is subjected to the condensate extraction pump discharge pressure which will vary from 25 to 40lb. per sq. in. gauge over the full load to shut valve pumping conditions.

High Pressure Heaters. These heaters are designed for operation on the discharge of the feed pump and are, therefore, subjected to the boiler pressure plus a margin of, say, 150/200lb. per sq. in. gauge on the feed water side. On the shell side they are, of course, subjected to the bled steam pressure associated with the required outlet feed temperature. The design is such as to permit any differential expansion to take place between tube bundle and shell. They are generally constructed with hairpin type tubes arranged in multipass form on the water side. The tubes are expanded in and bellmouthed, and the material is dependent on the heating steam temperature. Normally solid drawn copper is used. Cupro-nickel and Monel tubes are satisfactory for high temperatures. The drains are taken through an orifice plate or drain trap to an appropriate heat exchanger in the system.

In certain high pressure heaters, an automatic bypass valve is incorporated which, in the event of a burst tube, and consequent flooding of the heater, automatically cuts the heater out of the feed system, bypassing the damaged unit and permitting the feed water to flow direct to the boiler feed regulator.

Main, Auxiliary and Harbour Service Feed Pumps

The type of main, auxiliary and harbour service feed pumps to be fitted is determined primarily by the heat balance for the feed system and also whether steam or electricity is available in port. Over 5,000 s.h.p. it is preferable generally to fit steam turbine driven main feed pumps. In most ships these are of the centrifugal type (Fig. 12), but in one notable example, the "Beaver" Class, they are vertical multithrow reciprocating pumps driven through double reduction gearing (Fig. 13).

Determination as to the type of pump to install is also based on pump efficiency, initial cost, ease of maintenance and space available. The turbine direct driven centrifugal unit has a pump efficiency of approximately 60-68 per cent, depending on volume handled and discharge head. It has reasonable first cost and its maintenance is relatively simple; it is a compact design and for a given output, etc., occupies the least space.

In the case of the turbine driven geared multithrow reciprocating unit, the combined pump and gear efficiency would be approximately 88 per cent. The initial cost would probably be between two and three times that of the centrifugal unit and, being a reduction-geared multithrow reciprocating set, it would require considerably more maintenance than in the case of the centrifugal unit; since there are a greater number of glands to be packed and a larger number of rubbing and wearing surfaces, it would occupy considerably more space than the centrifugal unit. The exhaust steam from either of these turbine driven units would be clean and could be used

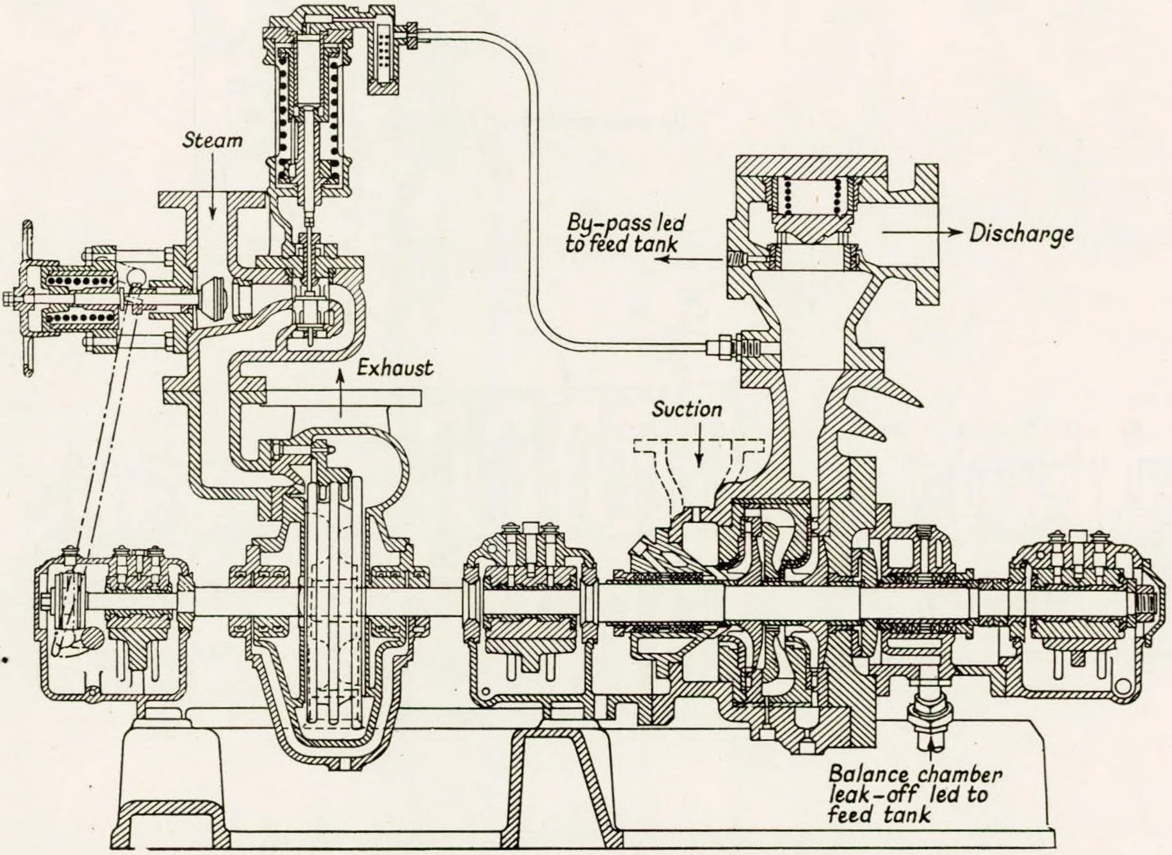


FIG. 12—*Two-stage turbine-driven centrifugal feed pump*

for feed heating, deaerating or evaporating purposes and then returned direct to the condenser.

In the case of the turbine direct driven centrifugal feed pump, the speed of the unit is fixed by the best operating speed of the pump, which is rarely the speed for maximum efficiency of the turbine under the required steam conditions. The turbines are generally of the impulse design, having one pressure stage and two or three velocity stages. The peak turbine stage efficiencies for single (Rateau) and two- and three-row Curtis wheels are of the order of 80, 68 and 53 per cent respectively. However, speed (r.p.m.), steam supply and exhaust conditions do not permit of the full advantage of these efficiencies being taken, due to the large adiabatic heat drop. It is considered, therefore, that these turbines could be run under suitable bled steam conditions to obtain the necessary adiabatic heat drop to give optimum stage efficiency, with a consequent saving in heat consumption and therefore increased plant thermal efficiency. The turbine, during manœuvring, could operate temporarily with boiler steam reduced to give the same pressure as the bled steam which would normally be used. On this basis, the turbine would, under seagoing conditions, be operated with bled steam, giving the requisite heat drop to obtain the optimum stage efficiency, and its exhaust could be used in evaporators or feed heaters. The steam would do useful work in the main engines before being used for feed pump turbine work.

There is more divergence of opinion in respect to auxiliary and harbour service feed pumps, but this is generally determined on whether steam or electric power is available in port, and on various other factors. There are the following alternatives:—

(*i*) Steam driven direct-acting reciprocating pump;
(*ii*) motor driven reciprocating multi-throw pump;
(*iii*) motor driven centrifugal multi-stage pump.

(*i*) The first does not call for any particular comment, being well known under various names at sea such as "up and down", "push and pull", etc.

(*ii*) For high pressure boilers a motor-driven geared multi-

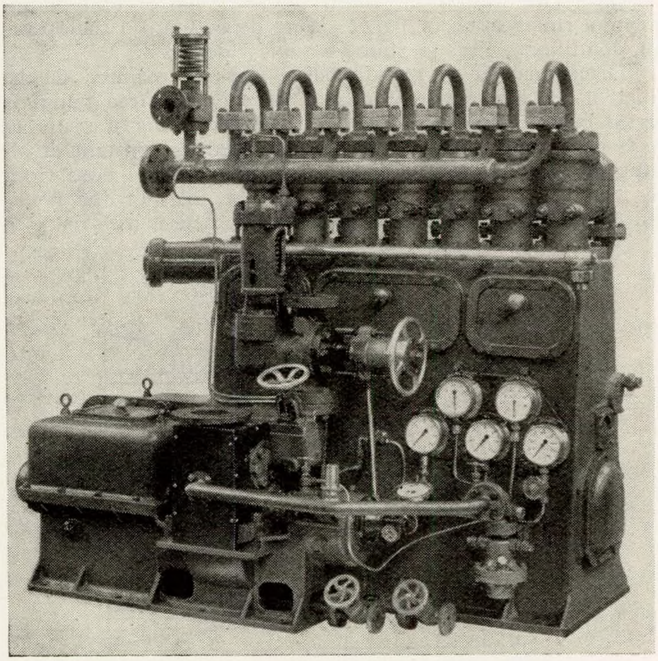


FIg. 13—*Turbine-driven multi-plunger boiler feed pump for 850lb. per sq. in. boiler pressure as fitted aboard the* Beaverdell *and sister ships*

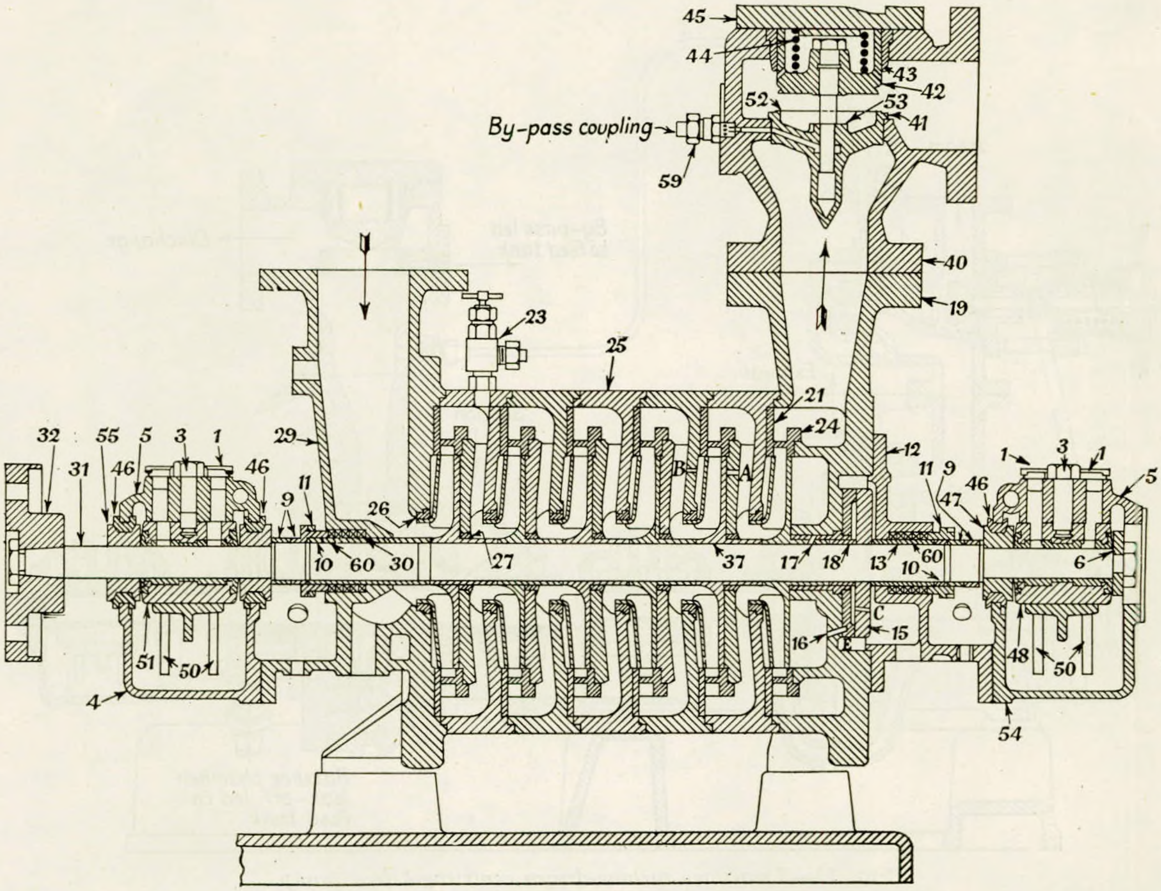


FIG. 14—*Electrically-driven centrifugal feed pump*

throw horizontal pump has been developed, a typical example being the pump fitted in the *Orcades*.

(*iii*) This unit is the Electrofeeder design of feed pump, having a ring section or barrel casing depending on the operating conditions; Fig. 14 shows a typical design.

Determination of the discharge pressure required at the outlet of the non-return discharge valve on the feed pump is carried out as shown in Fig. 15. The operating pressure in the boiler drum is known and is indicated as constant at all outputs. To this pressure is first added the static head from the feed pump suction centreline to the inlet of the boiler feed regulator on the boiler drum. An estimate is then made to obtain the curve showing the friction loss in the system at various outputs, allowing for piping, valves, heat exchangers, etc. This loss varies approximately as the square of the feed flow in the system and can be quickly estimated, using full output as a datum. The point at which this curve cuts the full power feed flow gives the pressure at the boiler feed regulator inlet. A further increment of pressure must be added to cover the drop in pressure across the boiler feed regulator. This drop in pressure varies for different types of boiler feed regulators, but a reasonable figure to allow for satisfactory control would be 50lb. per sq. in. gauge. This final figure gives the design outlet pressure at the feed pump discharge valve.

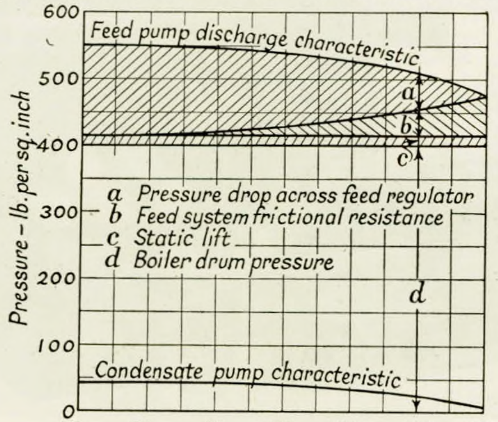


FIG. 15—*Estimate of feed pump discharge pressure*

If the feed pump is of the centrifugal type, the characteristic discharge curve would rise steadily to the shut valve condition pressure, which would be approximately 5-10 per cent higher than the normal full power discharge pressure, depending on the design of impeller. The shaded portion of the graph indicates the pressure difference, between system and pump characteristics, which is broken down over the boiler feed regulator. It will be seen, therefore, that the smaller the rise from full load to shut valve, subject to satisfactory governing, the less the power consumption of the pump will be.

In determining the feed pump discharge pressure required, no account has been taken of the pressure available from the extraction pump, since under certain emergency conditions the feed pump would require to draw direct from the feed tank and must therefore be able to provide the required full load discharge pressure when operating with a low static positive suction head.

Boiler Feed Regulator (Fig. 16)

A number of types of boiler feed regulators are available but only certain of these are satisfactory for marine operating

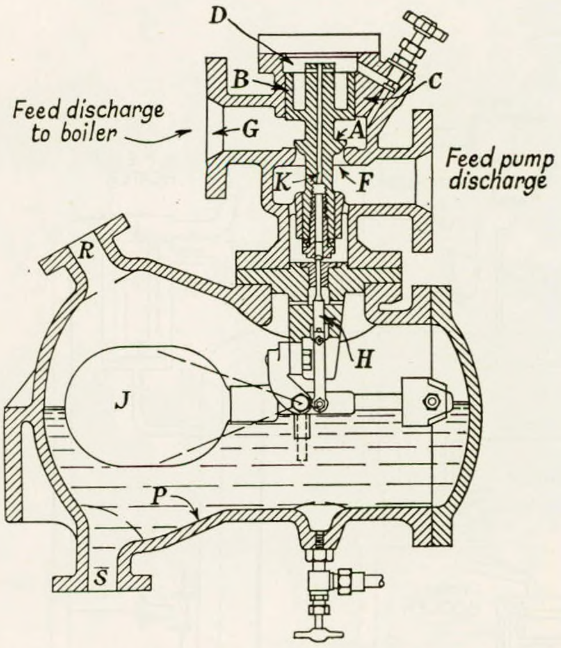


FIG. 16—*Boiler feed regulator*

conditions, which are much more arduous than land boiler requirements.

The Weir robot feed regulator has been successfully fitted to most types of marine boilers. This regulator is of the float controlled type.

The valve is of the non-return type and is mounted on a float box fitted with a float operated and fulcrumed needle valve H. The non-return valve has a dashpot piston B approximately twice the area of the valve seat A and has a hole K bored centrally, permitting feed pump discharge pressure to communicate with the dashpot cylinder D, the needle valve controlling the supply. The piston is an easy fit in the cylinder, enabling a certain predetermined leakage to take place through the dashpot clearance annulus. The float box P is fitted with balance connexions R and S to the boiler drum, to ensure that the same water level obtains in float box and drum.

It will be seen from the sectional arrangement that boiler pressure acts on the underside of the dashpot piston B and on top of valve A, whilst feed discharge pressure acts on the underside of A. The pressure in chamber D varies, maintaining the valve in equilibrium at all feed flows. Assuming that the boiler has been steaming steadily about half glass and the level begins to fall, float J also falls and the needle valve rises, cutting off flow to the top of the piston from the feed pump side. The pressure above the piston falls, due to leakage through the annulus clearance, until the pressure is insufficient to maintain the valve in equilibrium and it therefore rises to pass water into the boiler. Valve A only rises as far as the needle has risen, since, when that position is reached, the needle valve is uncovered, allowing flow to take place with consequent pressure build-up above the piston until equilibrium is again obtained. The reverse cycle takes place with rising water level. The normal working level varies from top position, when no steam is being produced, to bottom level or maximum drawoff, and feeds steadily at these and all intermediate positions. A small bypass is fitted to enable hand feeding to be carried out if necessary.

FEED WATER FILTERS

In the case of marine installations where the main propulsion or auxiliary machinery is of the steam reciprocating type, the feed water can be contaminated by the engine cylinder lubricating oil. This oil, if allowed to pass to the boilers, results in perforated boiler tubes, etc., and it is of extreme importance that all possible steps be taken to reduce the proportion of oil in the feed water to the absolute minimum. A number of methods and types of filter are employed to obtain a low oil content and these can be fitted on the low pressure or the high pressure side of the feed system, depending on the application. Certain installations carry feed filters of the cartridge type, having terry towelling, coconut fibre, diatomaceous earth or other forms of filtering medium. These cartridges can be fitted as a separate unit or incorporated in the main feed tank. The feed water passes through the drain cooler into these filters at a temperature of, say, 120-140 deg. F., to assist collection of the oil. High pressure filters are fitted in the feed pump discharge piping and are generally designed with a bypass arrangement, enabling the filter to be removed if necessary whilst the plant is in operation, should the pressure loss across the filter, due to its being dirty, become excessive. To ensure trouble-free operation of watertube boilers it is essential that the oil content of the water should not exceed 0·5 parts per million of the feed water.

HARBOUR SERVICE DEAERATING PLANT

Fig. 17 shows the present type of marine deaerator. This form of deaerator is designed particularly to operate with oily or greasy exhaust steam in harbour. The heating steam is not in direct contact with the feed water, being led through two separate U-tube heaters operating in parallel. The feed water follows a tortuous path to obtain good heat transfer and ebullition, so ensuring fully deaerated feed water.

This type of deaerator could also be arranged in an existing open feed system to enable deaerated water to be supplied to the boilers. An example of this form of feed system is given later in the paper (Fig. 18).

A deaerator can also be fitted in the closed feed system to enable double deaeration to be carried out where exceptionally high purity feed water is required. When utilized in the closed feed system it can be used as a collecting vessel and heat sump for all clean drains.

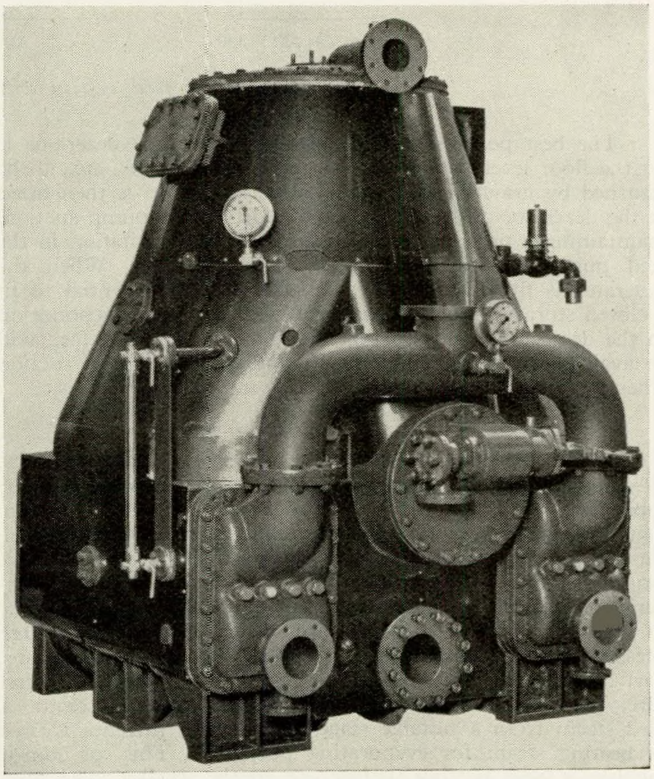


FIG. 17—*Marine deaerator*

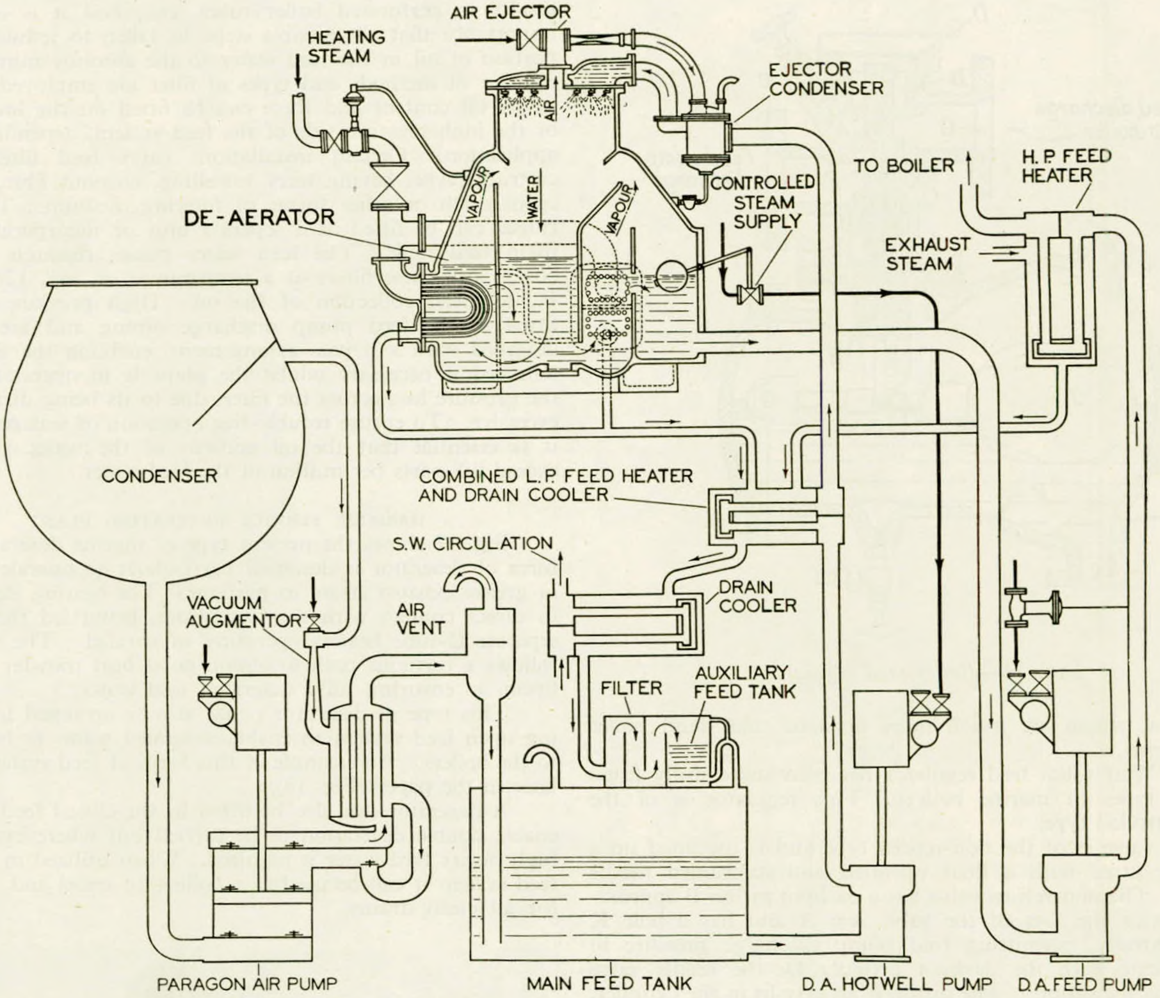


FIG. 18—*Marine feed system with deaerator and direct acting pumps*

The best position in the engineroom for the deaerator is on the floor level, which enables feed heater drains, etc., to be returned by gravity. A booster extraction pump is then fitted at the deaerator outlet discharging into the feed pump suction, maintaining a pressure therein and preventing cavitation in the feed pump due to flashing of the condensate. When the deaerator is fitted in an elevated position it is essential to fit a closed storage tank underneath it with a common connexion to the deaerator to ensure that a suitable capacity of feed will be available to prevent any trouble at the feed pump suction when operating under varying loads.

EVAPORATING PLANT

The evaporating plant in marine service, shown in Figs. 19 and 20, mainly comprised single evaporators of various capacities, for which the heating steam was live boiler steam. This arrangement, whilst not thermo-dynamically economical, was satisfactory from the point of view of minimum space requirements and minimum costs, since the high mean temperature difference available enabled a small heating surface to be utilized for a given output. This degrading of high pressure boiler steam is not acceptable in large installations, particularly with the present high cost of fuel. We find, therefore, that where high output of distilled water is required, bled steam from a suitable stage of the main turbines is used as heating steam for evaporating purposes. This, of course, involves a large heating surface due to the smaller mean temperature difference available for operation. A notable example of this is the *Himalaya,* whose evaporating plant has an output of 300 tons per day when operating on bled steam. In addition, these large output evaporating plants have chemically treated feed to reduce the scaling effect to a minimum. The chemicals are mixed in special tanks before being introduced into the feed supply to the evaporator generally in the same manner as boiler compounds are supplied to the main boilers. It should be pointed out here, however, that distillation alone of the feed supply to boilers is insufficient and it is essential to have deaeration also of the feed water to ensure freedom from corrosion.

When operating an evaporator without preconditioning of the feed, it is suggested that the evaporator should operate with a density not greater than 2/32nds. If possible, however, it would be better to operate with a density of 1½/32nds, maintaining the lowest possible evaporator shell temperature under all conditions, as this provides a softer scale which is more easily removed. Operating on this lower density means carrying a larger blowdown and consequently a greater consumption of heating steam. With the lower density, however, the period required between descaling shutdowns is considerably increased. It is, therefore, a balance between increased steam consumption and longer operating conditions before descaling and it is generally left to the superintendent engineer to determine the necessary compromise. Present day practice with high pressure watertube boilers is to double distil seawater before using it for boiler feed purposes, or alternatively to use single distilled shore water where available.

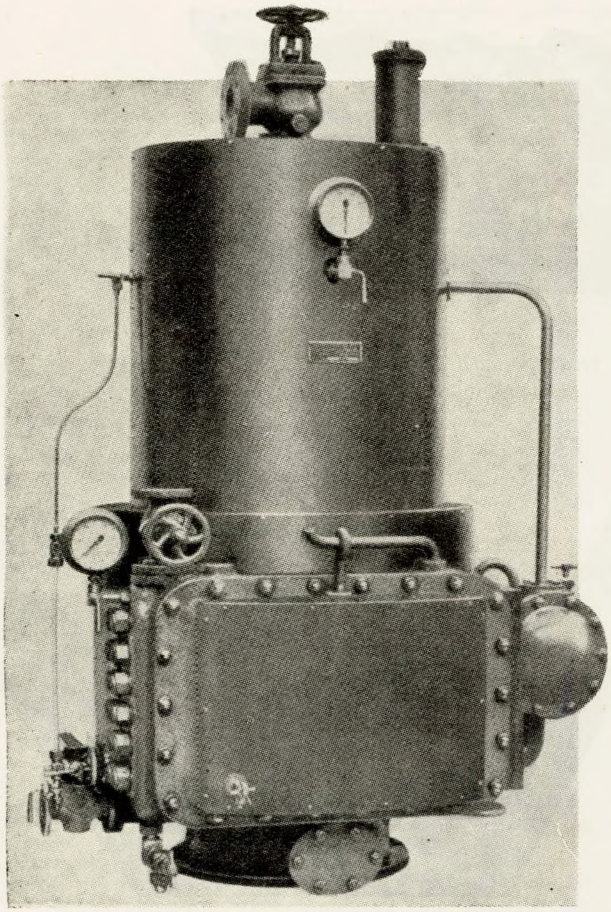


FIG. 19—*Marine coil type evaporator*

AUXILIARY STEAM GENERATOR

This steam generator is for the purpose of supplying saturated steam for the auxiliaries. It functions normally in the same manner as an evaporator, the heating steam being live boiler steam introduced into the steam box, flowing through steel tubes and producing saturated steam at the required pressure. The general construction of the steam generator is generally similar to an evaporator but suitably proportioned for the higher operating pressure.

SPECIMENS OF MATERIALS SUBJECTED TO CORROSION

Fig. 21 shows steel feed piping and boiler tubes which have been subjected to corrosion.

TYPICAL FEED SYSTEMS

Generally speaking, for powers over 5,000 s.h.p. it is advisable to fit a closed feed system, particularly where water-tube boilers are fitted. Fig. 22 shows a closed feed system for 5,000 s.h.p. where certain auxiliaries are fitted with steam reciprocating, and others with steam turbine prime movers. It will be observed that the greasy exhaust steam is taken through the primary feed heater, the drains of which are cooled in a drain cooler before passing through a filter into the drain tank. In the case of the steam turbine driven auxiliaries, the exhaust is led to the main engines and can be used in a low pressure stage, or, alternatively, it can be taken to the auxiliary condenser. The heating steam for the secondary feed heater is taken from the bled steam connexion on the main engines and the drains from the heater are taken through a separate drain cooler back to the drain tank.

Fig. 23 shows a closed feed system with a single evaporator. The vapour from this evaporator is taken to the l.p. feed heater, thence through the drain cooler back to the main condenser. There is an alternative connexion whereby the vapour can be taken direct to the auxiliary condenser, depending on the type of raw water supplied. The heating medium for this evaporator is bled steam from the main turbine.

Fig. 18 shows a marine open feed system operating with a deaerator and direct acting pumps. All feed water is deaerated before entering the suction of the main feed pump, after which it passes direct through an h.p. feed heater to the boilers. The heating steam for this deaerator is oily exhaust and it does not come into contact with the feed water since the deaerator is of the surface type, having U-tube heating elements. The drains from the heating elements are taken through a combined l.p. feed heater and drain cooler circulated with the ingoing feed supply to the deaerator. The drains from this heat

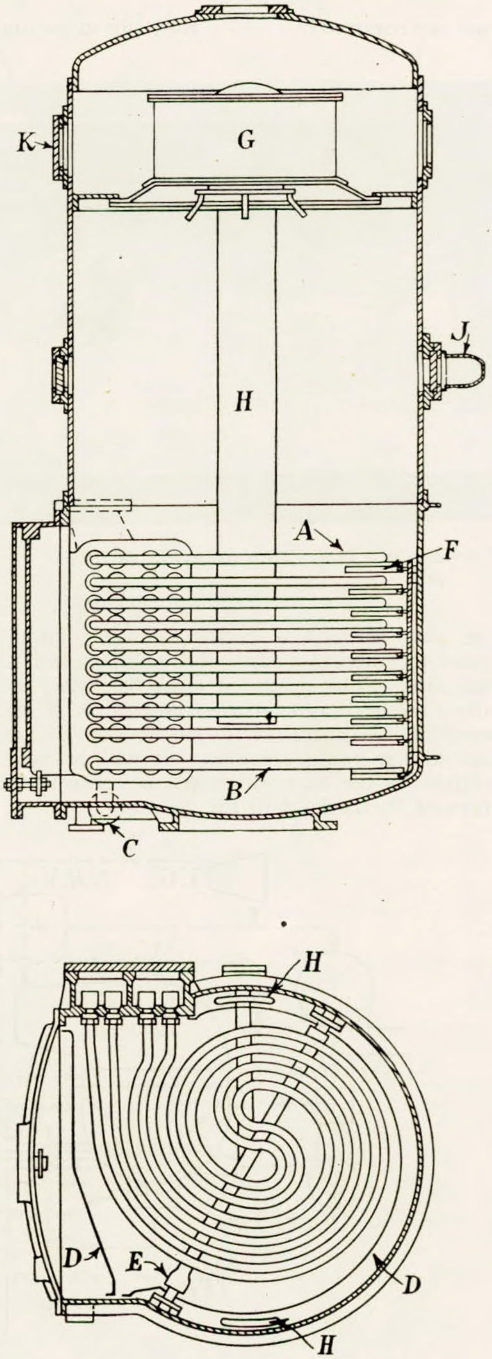
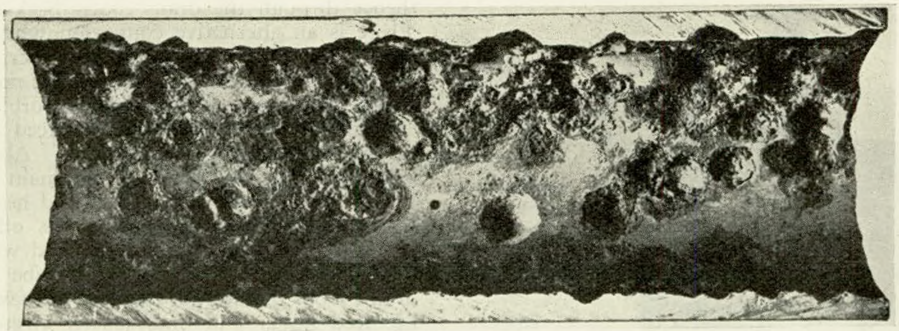
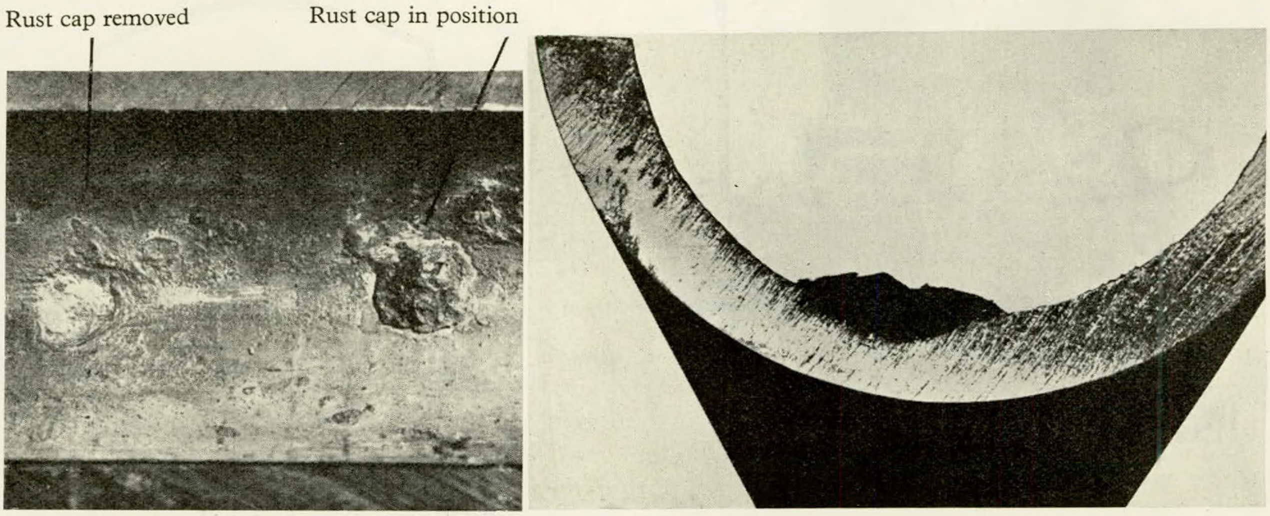


FIG. 20—*Evaporating plant*



Corrosion and pitting in a steel feedpipe with aerated water



Section of a boiler tube showing pitting

Section of a boiler tube showing a pit with rust cap in position

FIG. 21

exchanger pass through a further seawater circulated drain cooler prior to entering a filter and auxiliary feed tank to the main feed tank. The deaerator must be placed at a suitable height above the feed pump suction, determined by the deaerator feed water outlet temperature, to ensure that flashing will not take place in the pump chamber. It will be noted that the steam supply to the Hotwell pump is controlled by a float valve operated by the level in the deaerator.

Fig. 24 shows an open feed system of a type generally fitted in land installations. In this case the deaerator is of the direct contact type supplied with clean steam introduced to the deaerator by means of an automatic steam control valve set to maintain a given pressure in the deaerator shell and so control the outlet temperature of the deaerated water. In this type of system the deaerator is fitted with supply and extraction pumps referred to as the "lift" and "booster" pumps

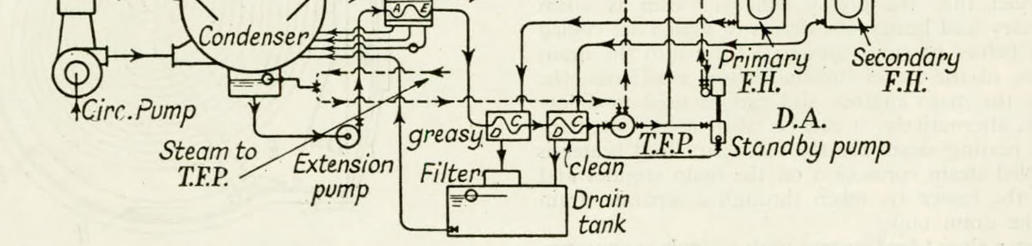


FIG. 22—*Closed feed arrangement system to use greasy exhaust steam*

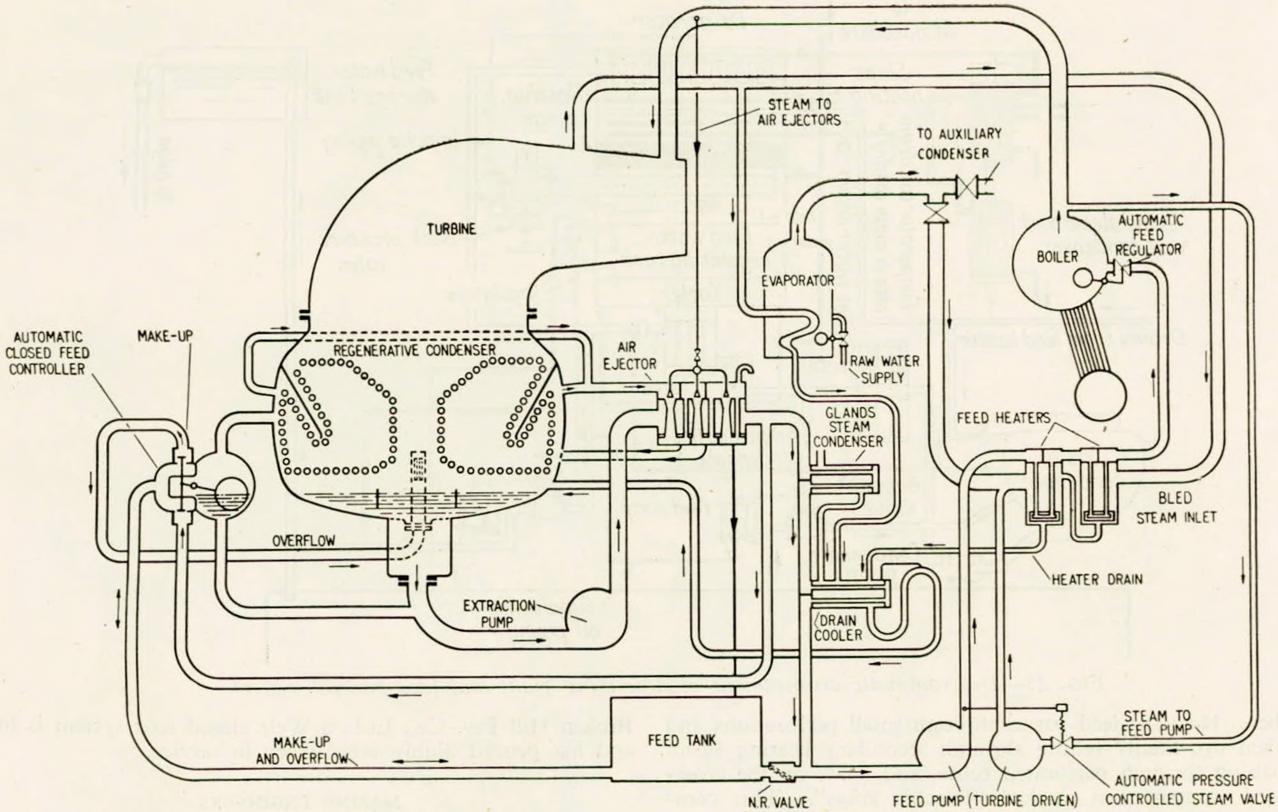


FIG. 23—*Diagrammatic arrangement of a steam power plant with regenerative main condenser, closed feed system, regenerative feed heating and evaporating plant*

respectively. The fitting of the lift and booster pumps enables the feed tank and deaerator to be kept at a relatively low position, the lift pump giving the necessary head to pass the water through the float controlled water inlet valve, whilst the booster pump extracts the hot deaerated feed water and discharges it at a pressure sufficiently high to ensure that there will be no flashing or cavitation in the suction of the main centrifugal boiler feed pump. The deaerator is fitted with an air ejector and condenser for sub-atmospheric operation. The ejector condenser is circulated with the ingoing feed water supply to the deaerator, thus increasing slightly the temperature of the feed before entering the deaerator spray chamber. In certain cases the deaerator is fitted with a vent condenser or, as it is sometimes named, "devaporizer", which handles the vapour outlet from the deaerator when it is operating at or above atmospheric conditions.

Fig. 25 shows the feed system as fitted to the German "Narvik" class destroyers which were in action during the recent World War. Briefly, the operation of the system is as follows: The condensate pump takes the condensate from the main condenser, circulating it through the air ejector, then through a "cooler" into the top of the deaerator distribution

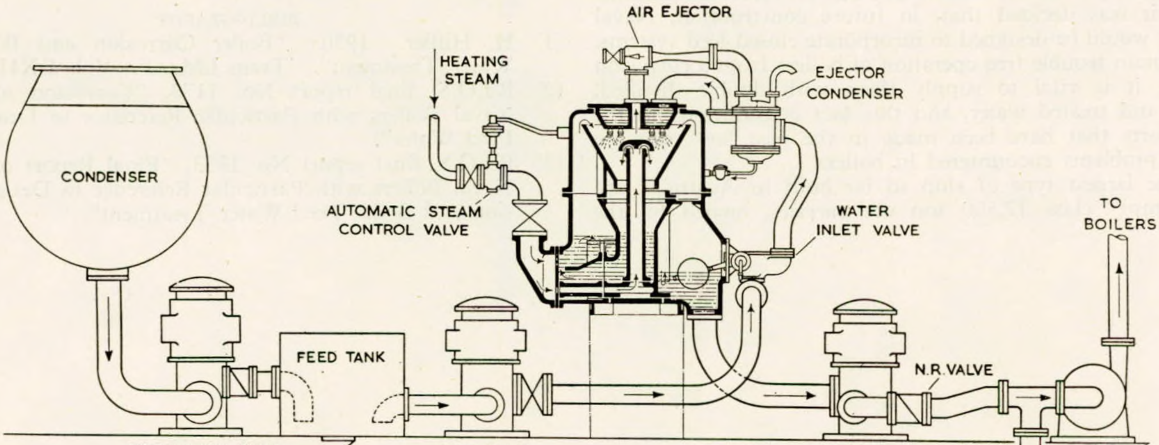


FIG. 24—*Diagrammatic arrangement of an open feed system with deaerating plant*

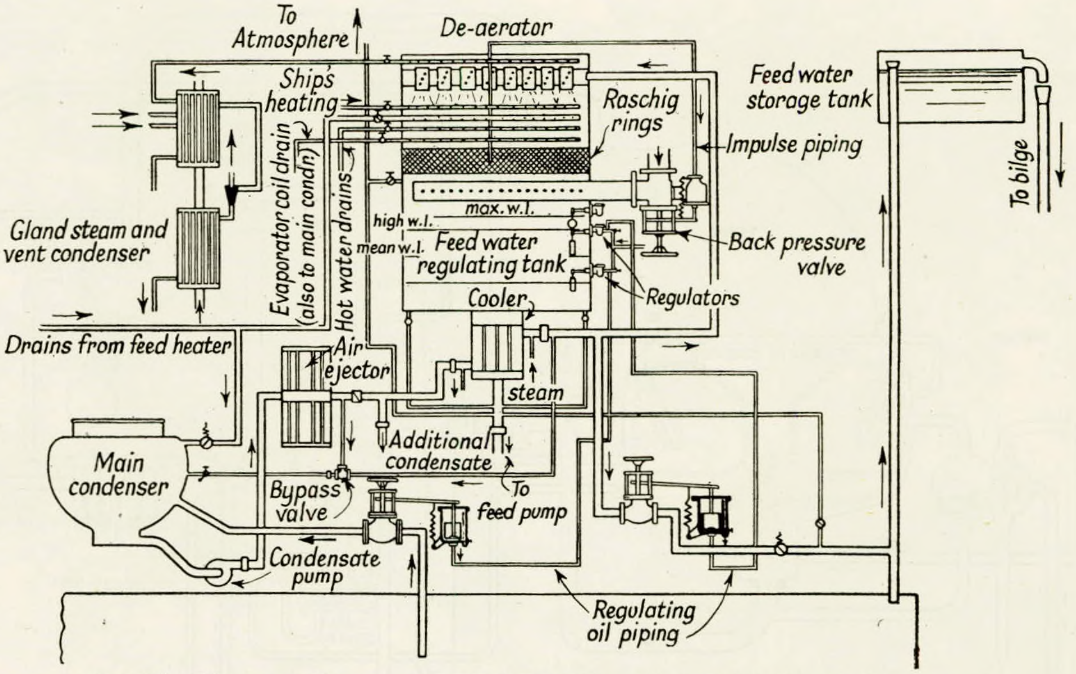


FIG. 25—*Diagrammatic arrangement of deaerating plant and feed control system*

chamber. Here the feed passes through small perforations and is broken up, finally falling through secondary heating steam also issuing through perforated tubes, and lands on the cross-sectioned compartment marked "Raschig rings". This compartment is filled with small rings or metal discs tightly packed to give the maximum effective heat transmission area. The main heating steam is introduced below and rises through the Raschig ring compartment, giving a contraflow effect in relation to the falling condensate. The effect of the heating steam in each case is to atomize the condensate and so produce effective deaeration. The deaerated water then passes through a heat exchanger marked "cooler" which heats the ingoing feed to the deaerator and cools the outgoing deaerated feed to a temperature suitable for the suction operating conditions of the main feed pump. This deaerator was fitted with a multiplicity of oil operated control valves which gave considerable difficulty in operation, to such an extent that manual control of the system was finally required. This system is in effect an open feed system fitted with a deaerator. Operation of this class of vessel proved unsatisfactory, due to corrosion difficulties, and it was decided that, in future construction, Naval machinery would be designed to incorporate closed feed systems.

To obtain trouble free operation of boilers from a corrosion viewpoint, it is vital to supply them with double distilled, deaerated and treated water, and this fact is confirmed in the many reports that have been made in the past few years on corrosion problems encountered in boilers.

In the largest type of ship so far built in Australia, the "Iron Yampi" class 12,500 ton ore carriers, owned by the Broken Hill Pty. Co., Ltd., a Weir closed feed system is fitted and has proved highly satisfactory in service.

MARINE ENGINEERS

It will be seen from the foregoing that the present day marine engineer in charge of high pressure high temperature boiler plant must, of necessity, be also something of a chemist if he is to maintain his equipment in good condition and keep the ship at sea, except for essential overhauls, for the maximum possible period. In the larger ships which have come on to the United Kingdom-Australia route, the engineer has a separate room in the nature of a laboratory in which he can carry out the various tests required on each watch for satisfactory operation of the machinery under his care.

ACKNOWLEDGEMENT

The author wishes to make acknowledgement to G. and J. Weir, Ltd., for permission to reproduce in this paper the various auxiliaries of their manufacture.

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INSTITUTE ACTIVITIES

Dinner of the Combined Councils of the Institute of Marine Engineers and the Institution of Naval Architects

The dinner of the combined Councils of the Institute and the Institution of Naval Architects was held on Thursday, 9th October 1952, at the Grosvenor Hotel, and was attended by the following:—

Institute of Marine Engineers

Vice-Presidents: Messrs. J. Calderwood, J. C. Lowrie, W. Sampson and Rear-Admiral(E) F. E. Clemitson, C.B.

Members of Council: Messrs. G. R. Chappel, J. E. Church, F. J. Colvill, R. Cook, C. P. Harrison, S. Hogg (Vice-Chairman of Council), H. R. Humphreys, O.B.E., A. Logan and A. Robertson, C.C. (Honorary Treasurer).

Secretary: Mr. J. Stuart Robinson, M.A.

Institution of Naval Architects

Honorary Vice-Presidents: Eng'r Rear-Admiral W. M. Whayman, C.B., C.B.E., and Sir Stanley V. Goodall, K.C.B., O.B.E.

Vice-Presidents: Sir Charles S. Lillicrap, K.C.B., M.B.E., D.Sc. (Chairman of Council), Sir Summers Hunter and Mr. V. G. Shepheard, C.B., R.C.N.C.

Members of Council: Messrs. J. Baird, K. C. Barnaby, O.B.E., J. Brown, F. C. Cocks, W. J. Ferguson, J. Lenaghan, J. A. Milne, C.B.E., A. R. Mitchell, M.B.E., M.C., J. M. Murray, M.B.E., R. B. Shepheard, C.B.E., S. Livingston-Smith, C.B.E., D.Sc., H. E. Steel, J. Turnbull, O.B.E., Vice-Admiral(E) Sir Denis C. Maxwell, K.C.B., C.B.E. and Professor E. V. Telfer, D.Sc., Ph.D.

Associate Members of Council: Sir Colin S. Anderson, Captain W. H. Coombs, C.B.E., R.N.R.(Hon.) and Instr. Rear-Admiral Sir Arthur E. Hall, K.B.E., C.B. (Treasurer).

Secretary: Capt.(S) A. D. Duckworth, R.N.(ret.)

Junior Section

Birkenhead

A meeting was held on Monday, 27th October 1952, at the Conway Street Secondary School, Birkenhead, when Mr. J. Brown gave a lecture entitled "The Construction of Steam Turbines" to a large audience. The lecture was delivered in an excellent manner and the author answered most efficiently the many questions which were asked in the discussion which followed. Mr. A. G. Arnold (Member) attended to represent the Institute at this meeting.

City and Guilds College

On Thursday, 6th November 1952, Lieut. Com'r(E) A. P. Monk, D.S.C., R.N.(ret.) (Member) presented his lecture entitled "The Construction of Marine Boilers" at the City and Guilds College, South Kensington. Twenty-two people attended the meeting, most of them students of the college. Mr. F. D. Clark (Associate Member of Council) represented the Council. The lecture was very well received and the lively discussion which followed was only terminated due to the lateness of the hour.

East Ham Technical College

A lecture entitled "The Construction of Marine Boilers" was given by Lieut. Com'r(E) A. P. Monk, D.S.C., R.N.(ret.) (Member) on Wednesday, 5th November 1952, to an audience of about 200 students at East Ham Technical College. The meeting was late in starting as it was necessary to arrange for further seating accommodation, the hall being filled to capacity. Owing to the unavoidable absence of the Principal, Dr. Jenkins, the Chair was taken by Mr. McDonald (Member), a senior lecturer on the college staff. Mr. G. F. Gatward (Associate Member) represented the Council.

Commander Monk, with the aid of an excellent series of slides, described the various processes involved in the manufacture of watertube boilers, with special reference to assembly and modern welding technique. A brief outline followed on the procedure for bringing a boiler into service. The lecture concluded with a description of the boiler units for the s.s. *Nestor*. After a period for questions, which was unfortunately curtailed owing to lack of time, a vote of thanks to the author for his excellent lecture was proposed by Mr. W. Geddes.

Mr. Gatward, in a short address, gave an outline of the qualifications necessary for admittance to junior membership of the Institute and an account of the activities of the Junior Section. He also expressed thanks to the Chairman, Dr. Jenkins, and the staff of the college, for their help and co-operation.

Greenock

Mr. Murdoch McAffer (Local Vice-President, Greenock) represented the Institute at a joint meeting of the Institute and the Greenock Association of Engineers and Shipbuilders held in the "Lorne", Greenock, on Tuesday, 7th October 1952. Mr. George Morrison, managing director of the Greenock Dockyard Co., Ltd., presided over a company of ninety members and visitors.

The lecture, well illustrated by lantern slides, which was given by Mr. J. K. W. MacVicar (Associate) on "Air Conditioning of Ships", covered every aspect of design and described the measures taken to overcome difficulties arising from varying climatic conditions and demands on the plant. Many questions were asked during the discussion which followed the lecture which were fully answered by the author.

Salford

On Tuesday, 4th November 1952, a lecture entitled "Photo-elasticity" was given by Dr. J. Ward, B.Sc., M.I.Mech.E. (Member) at the Royal Technical College, Salford. The Chair was taken by Mr. W. K. Rooney, B.Sc., Wh.Ex., M.I.Mech.E., head of the mechanical engineering department, and the meeting was attended by over one hundred senior students and visitors. After reviewing the history of the development of the photo-elastic method of stress analysis and mentioning the pioneer work of Professors E. G. Coker and L. H. G. Filon at University College, London, the author dealt with the construction of polariscopes, based on his experience in the use of different types over the last eighteen years. He then explained how the principal stresses and their directions could be obtained from the fringe pattern and mentioned that, since the maximum principal occurred on a free boundary, the designer could get valuable data from the boundary stresses. Numerous slides were shown illustrating the method applied to the determination of stresses in gear teeth, rolling mill housings, rings subjected to forced fits and keys, and the stress concentrations at fillets. He dealt briefly with the frozen stress technique used with three-dimensional models and mentioned the research work on pipe flanges that had been carried out at Huddersfield Technical College by one of his research students. The author concluded by pointing out the advantages of the method to the designer. The photo-elastic method enabled him to obtain the stresses on a complex shape which did lend itself easily to the determination of the stresses by calculation.

At the end of the lecture, many questions were asked, mainly on the plastics used for the construction of the models, the relating of the model results to the metal full-size component and to the accuracy of the method.

The Chairman then called upon Mr. A. P. Traill, O.B.E., Wh.Ex. (Local Vice-President, Manchester) to address the students. He mentioned the good work the Institute was doing in providing Junior Section lectures at various colleges and stressed the importance and advantages to students of joining the professional engineering institutions as soon as they were eligible for membership of the student sections. He mentioned that the Council of the Institute had introduced a scheme for probationer students and how, for the payment of quite a small subscription, these junior members could be kept up-to-date with the latest developments in marine engineering.

A vote of thanks to Dr. Ward, Mr. Traill and to the Institute was proposed and seconded by two members of the staff of the mechanical engineering department and carried by acclamation.

Membership Elections

Elected 12th November 1952

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