## THE WEIR CLOSED CIRCUIT FEED SYSTEM.

The primary feature of this system is that the feed water from the time it leaves the condenser until it reaches the boiler is contained in a closed circuit, so that no opportunity is presented for the absorption of air as arises in the usual feed tank installation, and the whole of the feed water from the reserve feed tank (in this case referred to simply as the feed tank) from drains, &c., is subjected to the de-aërating effect of the condenser before passing into the circuit. The air and incondensible vapours which are present in the condenser are removed separately from the water, and pass either to the atmosphere or feed tank. If this object can be satisfactorily obtained the deleterious action on the boiler surfaces due to the admission of air with the feed water can be eliminated.

As secondary features the system contains other differences from the ordinary system, viz., (1) means for securing a high degree of feed heating on the suction side of the feed pumps, which therefore renders the feed heaters much lighter than is obtained when they are fitted on the delivery side, and also less liable to derangement; (2) means for rendering the entire system from the condenser to the boiler automatic in action under starting, stopping and manœuvring conditions. This involves the use of a number of novel fittings subsequently to be described.

Other points to notice are (1) if the feed heaters are made of sufficient capacity to condense and cool the whole of the auxiliary exhaust under full power conditions, then, as in the usual turbine installations, this exhaust is the only portion of the steam contaminated by oil, only the resulting drain from the feed heater needs to be filtered, thus reducing the capacities of these fittings; (2) the feed tank can be placed low down in the ship as it is not necessary with this system to arrange for a suction head on the feed pump.

Up to the present this system has been fitted in five T.B.D's, viz., "Strenuous," "Seawolf," "Tourmaline," "Tyrian," and "Venomous." Two other T.B.D's of those cancelled subsequent to the Armistice would also have been fitted. In addition, some of the new liners building for the Cunard Company are also fitted. The systems in the T.B.D.'s show slight variations in a few particulars, but these will be indicated after the general standard arrangement and details have been described.

The system is shown in diagrammatic form in Fig. 1. The special fittings are —

Water extraction pump.
Air ejector.
Supplementary feed control valve.
Feed overflow valve.
Feed water heater.

Ejector heater condenser.
Ejector surface condenser.
Temperature regulating or control valve.

In a twin-screw installation as in the T.B.D's, with each side independent, the system is fitted in duplicate, one set for each main engine with suitable cross-connection valves and pipes between the extractor pumps, air ejectors and feed water heaters (*see* exceptions in " Tyrian " later).

*General Arrangement.*

The turbine-driven rotary water extraction pump, *B*, draws the condensed water from the condenser, *A*, and delivers it at a pressure of say 25 lbs. gauge through the small heater, *C*, and thereafter through the feed heater, *G*, to the suction of the feed pump, *H*. The steam-jet air ejector, *E*, withdraws the air and vapour from the condenser, *A*, and the steam used is condensed in the heater condenser, *C–D*, and drains into the feed tank, *N*, the air passing off through an air outlet pipe, *F*, at a suitable point on the apparatus. The heater-condenser, *C–D*, is in two parts, the lower portion, *D*, called the ejector condenser, using sea-water for circulating to ensure complete condensation and cooling of the ejector steam and vapour. In the event of the quantity of water required for the boilers on account of the feed pump slowing up or any other cause decreasing, the pressure rises in the extraction pump delivery pipe, and opens a spring-loaded valve, *K*, through which the surplus feed-water passes into the feed tank, *N*.

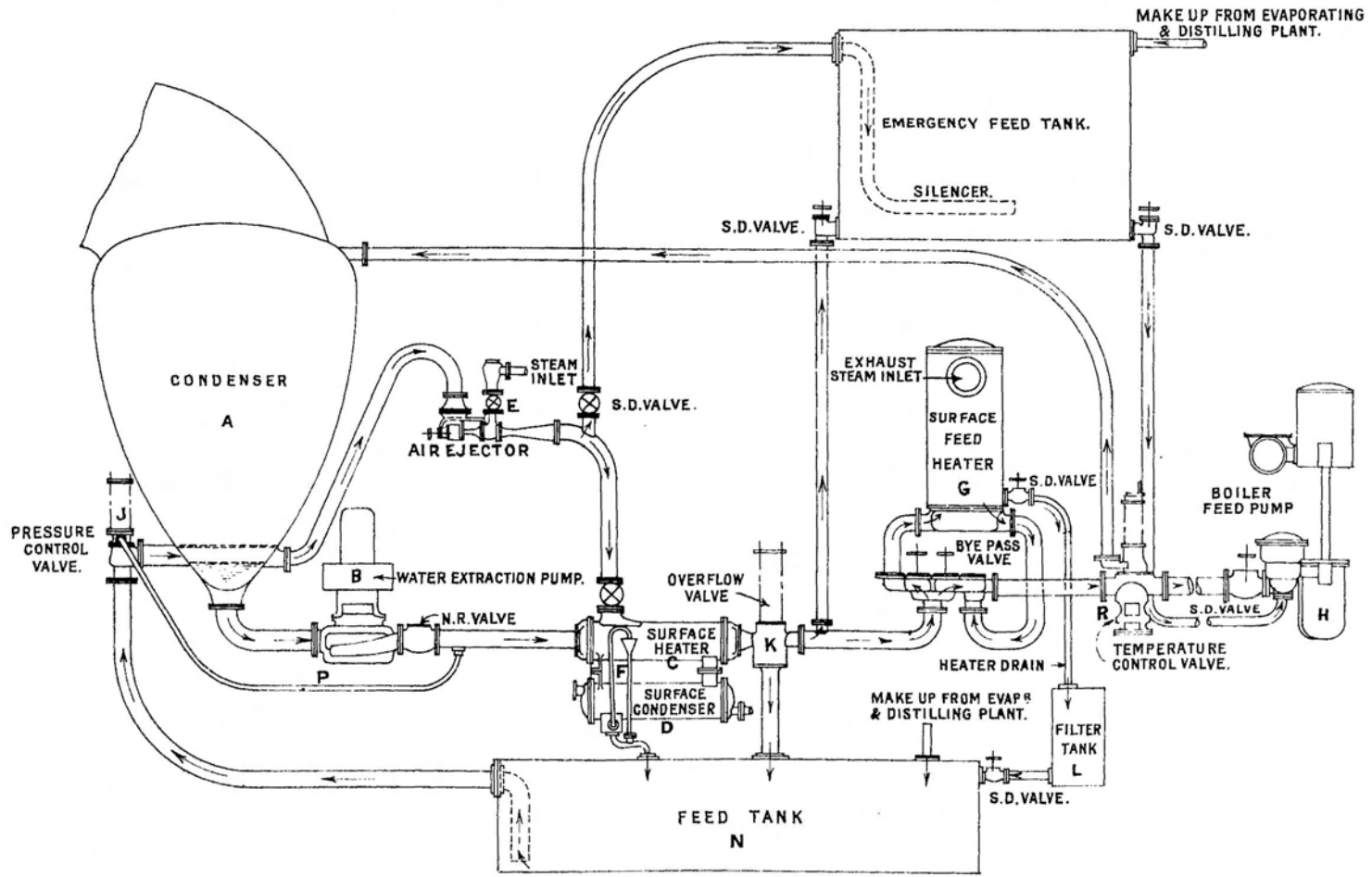
In the event of the main turbine being slowed up, or stopped, there will be a decrease in the quantity of water delivered by the extraction pump, and a consequent fall of pressure on the discharge which will be communicated through the pipe, *P*, to the supplementary feed control valve, *J*, which thereupon opens and enables the feed supply to be kept up from the feed tank and de-aërated in the condenser before passing to the feed circuit.

When running at reduced powers or in harbour the temperature regulating valve, *R*, operates, and automatically regulates the quantity of feed water passing through the feed heater, *G*, so that the whole of the auxiliary exhaust is condensed and cooled therein.

The auxiliary exhaust condensate is led through the filter, *L*, to the feed tank.

As in the T.B.D's the feed tank is placed low down, and is part of the hull structure, it is necessary to make provision for the emergency of this tank being holed or leaking from the sea. The additional arrangements necessary can be seen from the figure. The pressure control valve and relief valve are gagged in the shut position, the system then working as an open feed tank installation. The auxiliary exhaust now passes to the main condenser, and is delivered unfiltered to the boilers, this disadvantage being accepted in the emergency. One of the oil

# ARRANGEMENT OF CLOSED FEED CIRCUIT SYSTEM.

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fuel peace tanks in these vessels is fitted solely for the purpose of emergency feed tank.

## Descriptions of Special Fittings.

*Air Ejector.*

This is a two-stage steam ejector. The main portion consists of a group of 19 small nozzles of $\frac{5}{16}$-in. throat diameter, and the augmentor portion of one small nozzle of the same size. A non-return kinghorn valve is fitted at the air inlet connection to obviate against reversal of flow of the steam when starting up the ejector. The only trouble that can normally arise in working is the choking of the small nozzles, which may be caused by dirt or scale from the pipes. A steam strainer is provided to minimise this trouble, and the ejector is arranged so that it can be easily and quickly dismantled for cleaning.

*Water Extraction Pump.*

This pump is turbine-driven running at a practically constant speed of 2,300–2,400 revolutions per minute. A speed governor is fitted and so adjusted that these limiting revolutions are maintained when running empty or at full load. An emergency governor is also fitted to stop the pump if from any cause the designed speed is sensibly exceeded. Ball bearings and a ball thrust are provided. The pump is so constructed that it may be dismantled and overhauled without disturbing any of the steam or water connections. The pump is of the vertical design, this being necessary in the case of vessels fitted with underslung condensers so as to maintain a head of water between the lowest point of condenser and the pump chamber.

*Supplementary Feed Control Valve.*

The function of this valve is to maintain a pressure in the feed suction pipe. It has been already indicated that any water passing from the feed tank should be de-aërated before passing into the circuit.

This valve is a single-seated valve with a piston extension, and is also spring-loaded. When the pressure falls in the suction pipe the valve is opened by the spring, and water is drawn into the condenser; conversely when the pressure rises to a pre-arranged point the pressure which is led to the piston chamber shuts the valve against the tension of the spring. A special feature of this valve apart from its automaticity is that it opens quickly and closes slowly. This is due to the action of a small pilot valve which admits pressure to the piston chamber. This valve is of the non-return type, with a small leak groove cut across its face. The clear area of the valve is therefore available for the supply of water to the piston chamber, whereas only the leak-off is available when the valve is closing. A small strainer is also fitted in the supply pipe, *P*, to prevent the access of grit

which would tend to jamb the piston. Gagging arrangements are also fitted for running under emergency conditions.

*Feed Over-flow Valve.*

Any excess of water in the system passes through this valve to the feed tank. The valve is of the simple spring-loaded type with a dash-pot extension to prevent " chattering."

*Feed-water Heater.*

The heater is fitted with tubes of the ordinary condenser type with ferrules. It is six-flow as regards the feed water circulation, the feed entering and leaving at the bottom and passing through the tubes. It is two-flow as regards the exhaust steam and condensate, the first flow being around the last five passes of the feed circulation. The second flow is around the first pass of the feed circulation, the exhaust condensate being therefore cooled in this section and passing to the drain at a temperature not exceeding 150° F.

*Ejector Heater and Surface Condensers.*

The heater condenser is fitted with tubes of the ordinary condenser type in the same manner as the main surface feed heater.

The feed water passes through the tubes of the top or heater portion and the sea water passes through the bottom or condenser portion. The discharge from the air ejector enters the heater, and in the course of its passage through that apparatus transfers its heat to the feed water. The circulating water for the condenser portion is taken from the main circulating pump. The condensed steam with air and uncondensed vapour passes from the heater into the bottom or condenser portion where the vapour is condensed. The air and condensate are also further cooled, thus preventing vapour blowing into the engine-room. The water drains out at the bottom of the condenser and the air escapes from an open-ended pipe on this drain to the engine room.

*Temperature Regulating Valve.*

The temperature regulating valve is provided to meet the condition which arises when the water extraction pump is not discharging a sufficient quantity of feed water to condense all the exhaust steam. When this happens the outlet temperature of the feed water from the heater becomes excessive. The increase in temperature opens the temperature regulating valve, and allows some of the hot feed to flow back to the main condenser. The water enters the condenser at the top and is cooled in its passage down through the cold tubes. A circulation is thereby set up through the main feed heater and the main condenser, thus condensing the whole of the auxiliary exhaust at reduced powers.

The valve is opened by the vapour pressure of a sensitive fluid contained in a hermetically-sealed metallic bellows of special design, and is closed by a spring.

Gear is provided so that the valve may be operated by hand if desired; and an adjustment is fitted by means of which the valve can be set to open at any desired temperature.

*Variations from Standard Arrangement.*

The heater portion of the ejector condenser has been omitted in all T.B.D.'s except "Tyrian," as the exhaust steam under all conditions of steaming is sufficient to heat the feed water to the desired temperature, and this fitting is therefore unnecessary in these vessels. Except for this modification, "Seawolf" and "Strenuous" are fitted with the standard arrangement. "Venomous" is fitted with turbine-driven feed and circulating pumps, and "Tourmaline" with geared turbine driven boiler-room fans (in this latter connection the only vessel in H.M. Navy so fitted). Independent exhaust ranges are fitted in these vessels for the turbine and reciprocating auxiliary exhausts, only the latter of which is normally used on the feed heater, the other, which is free from oil, being led to turbines or condensers. Under slow and moderate conditions the feed heating effect is all that is desired and no efficiency is sacrificed, but theoretically there should be a slight loss of efficiency at full power. The variation of efficiency in the standard closed system over the open system is, however, under normal conditions small and the modifications combined with the special details in these vessels do not sensibly affect the efficiency at full power.

A modified design of feed heater is fitted in "Venomous," this fitting being in two parts, the cooling portion being a separate detail from the condensing portion. This obviated some casting difficulties in connection with the division of the heater into two-flow for the exhaust steam in addition to improving the efficiency of the cooling portion by its removal from contact with the hot exhaust steam. The arrangement in "Tyrian" exhibits the widest variations from the standard system. Three air ejectors are fitted, the centre as a reserve for either side in the event of choking or inefficiency of the port or starboard ejectors. The three ejectors discharge to a common condenser, and in this case the heater portion of the ejector condenser is fitted. The extraction pump deliveries combine before passing through the heater condenser, and a single lead is taken forward to the feed heater, one only being fitted. The auxiliary exhaust is led either to the heater or turbines, a sponge filter being fitted to the extractor pump delivery range just before the heater. The auxiliary exhaust condensate from the heater is not separately filtered. The temperature regulating valve of the automatic type is dispensed with, a screw-down type being fitted in lieu. Under running conditions the temperature of the feed is arranged for, as in the open installation, by suitably

proportioning the amount of exhaust steam between turbines and heater or by hand regulation of the temperature valve in harbour and when manœuvring.

*Experience on Trials and under Service Conditions.*

The system has worked satisfactorily on service and has been found equal in reliability to the ordinary open installation. No difficulty has been experienced generally with the automatic details of the system, the only defects experienced being such as might be expected with any similar fittings. Erosion has been experienced in the impellers of the extraction pumps, slight damage to the impeller of one pump in another vessel, in each case necessitating renewal. The vacuum maintained by the ejectors has generally been of a higher order than that given by the ordinary air pump system. It has been found necessary to give ample clearance in the plunger rings of the feed pumps, owing to the high feed temperature, but the life of the rings does not appear to be affected. It would appear from the standard design of the system that wear of the extractor pump impellers due to erosion must be anticipated. The pumps are high duty pumps and are able to deliver their full output with a very small head of water, of the order of 8 in. on the suction side. This means that with fluctuations in the system, which even under steady running conditions apart from manœuvring are always present, the suction side of the pump is partially emptied till the automatic make-up valve is brought into operation and the flow re-established. This making and breaking effect of the current is a fruitful source of erosion, as it produces hammer effects due to the sudden collapse of cavities, the erosion being most marked at the discharge side of the impeller. This effect is under consideration and means have been devised to anticipate the emptying of the suction side of the pump by controlling the automatic make-up valve by a small float arrangement on the condenser.

There is insufficient experience at present to speak with confidence as to the reduction of corrosion in the boilers. Generally speaking, the boilers of the vessels so fitted are in good condition and are reported to open very clean. It might be anticipated that a more marked advantage in this respect over the ordinary system would accrue in vessels where the boilers are subject to more continuous working than pertains in war vessels.

Under full power conditions with this system the whole of the latent heat in the auxiliary exhaust steam is transferred to the feed water. The turbines are, however, deprived of the gain in power that would accrue from the utilisation of this steam in the L.P. turbines, and an increased quantity of main steam must be supplied direct to the H.P. turbines to compensate for this loss of power. An additional output of steam from the boilers is therefore necessitated, but due to the higher feed obtaining with the closed system, the net effect is to show theoretically a

slight grain in overall efficiency, which in the general case should be about 3 to 4 per cent.

At reduced powers due to the action of the temperature regulating valve some of the latent heat in the auxiliary exhaust passes indirectly to the condensers. Moreover, at reduced power, the load on the ejector and extractor pump combination is greater than that required for the proportionate power being developed and this detracts slightly from the overall efficiency. The gain in thermodynamic efficiency is therefore discounted by these considerations, and although a slight advantage may be seen at full powers, at very low powers experience has shown a slight reduction of efficiency compared with the ordinary feed system, although only of small magnitude.

To follow better the general scheme and details of the apparatus it is advisable to appreciate the heat interchanges that take place in the system, as these will serve to indicate the general proportions and reasons for some special fittings found necessary. This will be best understood by taking *approximate* figures for a 27,000 S.H.P. T.B.D. in which the installation is fitted.

(1) *At Full Power.*

Turbine steam at 12 lbs.
per S.H.P. hour = 324,000 lbs. per hour.
= 90 lbs. per second.
Auxiliary steam, 52,000 lbs. per hour = 14·4 lbs. per second.
Exhaust steam pressure = 20 lbs. gauge.
,, ,, temperature = 259° F.
Latent heat in exhaust steam = 820 B.T.U's per lb.,
assuming it contains $12\frac{1}{2}$ per cent. of moisture.
Feed water delivered to heaters will be about 90° F.
The auxiliary exhaust condensate temperature = 150° F.
Then heat from the exhaust steam =

$$14{\cdot}4 \times (820 + 259 - 150) = 13{,}400 \text{ B.T.U's per sec.}$$

This heat goes to the feed water; therefore the temperature to which it is raised is

$$90^\circ + \frac{13{,}400}{90 + 14{\cdot}4} = 218^\circ \text{ F.}$$

(It should be noted that the quantity of feed passing through the heater is the total required by the boilers, *i.e.*, the sum of turbine and auxiliary consumptions.)

The feed water, neglecting radiation losses, will therefore pass to the feed pumps at a temperature between 210° F. and 220° F. To obviate any trouble with the feed pumps working with water at this temperature, it will be necessary for it to be under pressure. It is arranged for it to be under a pressure of 15 to 20 lbs. per sq. in. gauge in the feed suction range, for which the temperature of vaporisation is 250° F. to 260° F. The auxiliary consumption at full power and the various temperature conditions worked to will

govern the design of the feed heater, which will then naturally be of sufficient capacity for all other powers.

The question of the temperature of the drain from the heater is one which affects the vapour rising in the engine room from the feed tank. It also affects the choice of a suitable filtering material. To ensure that this drain temperature does not exceed 150° F., it is necessary to arrange in the heater for a special cooling portion so that the condensate leaves from the portion at which the comparatively cool feed water (90° F.) enters.

(2) *At Low Powers, say,* 2,700 S.H.P.

Turbine steam = 17 lbs.
per S.H.P. hour = 46,000 lbs. per hour.
= 12·8 lbs. per sec.

Auxiliary steam = 15,200 lbs. per hour = 4·2 lbs. per sec.

Temperature of turbine condensate = 80° F.

Then, with exhaust and condensate conditions as in the full power case, the temperature to which the feed water would rise, assuming the heat could be absorbed, is $t$, where $t$ is given by

$$(t - 80)\,[12{\cdot}8 + 4{\cdot}2] = 4{\cdot}2\,(820 + 109)$$
$$\text{and } t = 310^\circ \text{ F.}$$

As, however, the temperature of the auxiliary exhaust is 259° F., this figure could never be reached, but it indicates that a percentage of the feed water would be vaporised if under a pressure of 15 to 20 lbs. gauge, and it is not desired to exceed a temperature of 210° F. to 220° F. or admit the presence of vapour, from feed pump considerations. The normal supply of feed water is therefore under this condition of working not sufficient to condense and cool the whole of the auxiliary exhaust. To maintain the condition that the whole of the auxiliary exhaust is dealt with by the feed heater it is necessary to circulate more water through the heaters, and this involves the fitting and bringing into operation of return pipes from the feed delivery side of the heaters so that additional water over and above that required by the boilers is circulated through the heater.

(3) In the extreme case there is the harbour condition where the turbine steam is zero. Each lb. of auxiliary exhaust gives up, say, 929 B.T.U's in the heater. The rise in temperature of the feed water will be 120° F. to 130° F. The amount of feed water circulating through the heater will, therefore, be 7 to 8 times that required by the boilers.

The temperature regulating valve is fitted to control automatically this additional circulation.