THE ECONOMICAL DISPOSAL OF AUXILIARY EXHAUST STEAM.

It is now generally appreciated by engineers that very considerable losses may be incurred unless the exhaust steam from the auxiliary engines is disposed of in the most economical manner possible. The question is of especial importance in the Royal Navy, where the normal steaming is in general carried out at very low powers, under which conditions the heat available in the auxiliary exhaust aggregates a large proportion of the total output of the boiler.

There are three general methods whereby a portion of the heat in the auxiliary exhaust may be either returned to the boiler or else otherwise effectively employed. These are—(*a*) heating the feed by exhaust steam; (*b*) passing the exhaust to a suitable stage of the main turbines where it does useful work; and (*c*) using the exhaust as primary steam in the evaporators, thus replacing an equivalent quantity of boiler steam.

The relative values of these different systems are, of course, of great practical interest to the engineer, and it is the purpose of this article to discuss the factors involved, to indicate the usual order of merit, and to show how this latter may be departed from in individual cases.

(*a*) **Feed Heating by Exhaust Steam.**—This use of the auxiliary exhaust has been fully discussed in a previous article in these Papers (No. X, p. 63), from which it appeared that, provided ***all*** the heat in this system could be returned to the feed, then the demand upon the boilers would be limited to the heat equivalent of the brake horse-power of the auxiliaries, being sensibly independent of their actual steam consumption and design. Such a system constitutes in effect 100 per cent. efficiency as regards exhaust disposal, and is not feasible with any existing installation in the British Navy.

The degree by which the foregoing ideal is departed from in practice depends upon the type of feed heater and its arrangement in the system. There are at present two general lines upon which the feed heaters are arranged, namely:—

(1) The Contact Feed Heater, in which exhaust steam is mixed with the feed prior to the discharge of the latter to the feed tank. The pressure of the feed in such a heater is approximately atmospheric, the maximum temperature attainable without evaporation of the water being thus 212° F. The exhaust steam is used at 100 per cent. efficiency as far as such a heater is concerned, but

appreciable losses of heat occur by radiation and conduction from the feed water on its way from the feed tanks to the boilers, these losses becoming greater as the temperature of the feed is raised. It is generally impossible to dispose of the whole of the available exhaust steam by such means under all conditions of steaming, as to do so would entail raising the feed to an impracticably high temperature—that is, it would either boil or, even if this did not occur, it would be so hot that separation would occur in the feed suction system, accompanied by hammering in the pipes and pumps.

(2) The Surface Feed Heater, where the exhaust steam and the feed are separated by tubes or other suitable heating surfaces. The feed may be raised to any desired pressure before discharge to the heater, and thus the upper temperature limit may be in excess of 212°. It is practicable by this means to use the whole of the exhaust steam for feed heating, provided that the temperature attained by the feed in absorbing the available heat units is less than that of the exhaust steam itself.

Feed heating in this latter system may be effected at 100 per cent. efficiency, provided that the heat in the heater drainage water is returned to the feed system, and if no heat losses occur from the piping between the heaters and the boiler: this last factor may be rendered of small importance by arranging the heaters close to the boilers they supply and by efficiently lagging the feed discharge pipes from the heaters.

The arrangement of the heater drains is therefore of considerable importance, and is influenced principally by questions other than of heat conservation. The contact feed heater is open to the objection that any oil in the exhaust steam is directly mixed with the feed water, and though some deposition of oil may occur in the feed tank, no really efficient medium has yet been discovered which will effectively filter the feed at temperatures in excess of 120° F. to 140° F. (*vide* Papers, No. VIII, p. 67). It has been considered desirable, therefore, in view of the importance attached to maintaining an oil-free feed supply for highly forced water tube boilers, to fit surface feed heaters in the more modern vessels, making arrangements whereby the heater drainage water is first cooled and then filtered before its final discharge to the feed tanks.

This entails a loss of heat in the drain coolers, which, in ships fitted with an open feed system, will amount to about 10 per cent. of the heat available in the auxiliary exhaust.

In ships fitted with closed feed systems a further loss occurs, since the water discharged to the feed tank can only re-enter the feed system through the condensers, where it is cooled to the temperature of the main condensate. The loss of heat from the feed heater drainage system in such vessels is about 2 per cent. greater at full power than that incurred with an open feed system, and may be as much as 16 per cent. at low powers when the condensate temperature is lower on account of the reduced temperature difference required to effect the heat transference in the condenser.

The efficiency of this method of exhaust disposal therefore does not exceed about 90 per cent. under the most favourable conditions in existing naval installations.

It appears probable that with careful design of the turbine glands and oil baffles and given proper operation, the major part of any oil that does appear in the auxiliary exhaust will be derived from the reciprocating machinery. The modern tendency is to develop and instal rotary auxiliaries driven by steam turbines or by electric motors, thus not only reducing the extent of the saturated steam piping, but also rendering remote the possibility of oil in the feed. The necessity for cooling and filtering the heater drains ought not to exist if no reciprocating auxiliaries are fitted, and in such an installation it should be practicable to return the heater drainage water direct to the feed system, so saving the losses referred to. In an open feed system it would be discharged direct to the feed tank, but in a closed system a suitable pump would be required.

(*b*) **Use of Auxiliary Exhaust in the Main Turbines.**—This method of exhaust disposal is, of course, open to the objection that nearly the whole of the latent heat in the auxiliary steam is finally rejected to the main condenser and so lost. The gain to be realised depends entirely upon the amount of work that can be performed in the main turbines by the auxiliary exhaust, and the extent to which the consumption of main steam can be cut down thereby; these two factors must be weighed against the additional steam demand of the auxiliaries, due to working against a back pressure instead of exhausting to a vacuum.

The degree of economy is affected (1) by the percentage of full power being developed by the main engines; (2) by the positions at which auxiliary exhaust steam is admitted; (3) by the C.E. pressure; and finally (4) by the design of the auxiliary engines and of the main turbines.

(1) **Percentage of Full Power developed by Main Engines.**—The steam pressure at inlet to the main turbines is gradually lowered as the speed of the ship is reduced, and thus at low power exhaust steam of given pressure can be provided with a longer path in which to do work than is possible at higher power.

This does not necessarily result in more work being extracted from each pound of exhaust steam, because the efficiency of the blading falls off with the reduction in speed and output. At the same time, however, the increasing percentage of auxiliary exhaust (compared with the main steam supply) does mean that a larger fraction of the output of the main turbines can be obtained from the C.E. at low powers than at high ones. The possible gain due to the use of exhaust steam in this manner thus increases with reduction in the output of the main engines.

(2) **Positions at which C.E. Steam is Admitted to Turbines.**—It is evident that, in order to make full use of the exhaust steam, the position of admission to the turbines would require to be altered with each change of power—an obviously impracticable arrangement. Cases have been known where damage to turbines has been occasioned by the admission of exhaust steam, usually being due to the impingement of water carried in with the exhaust or else to distortion of the casing or rotor owing to the exhaust steam being admitted locally instead of uniformly round the circumference of the turbine. It is, therefore, the latest Admiralty practice to arrange that exhaust connections shall be confined to the receiver pipes of turbines, as far as the Reaction type is concerned: it is thus hoped that more uniform distribution of any moisture will be obtained, while local heating will be avoided. The probabilities of damage arising from such effects is less likely in Impulse than in Reaction turbines, and the provision of exhaust connections at intermediate stages in the former type is not uncommon, arrangements being made to direct the steam well clear of the blading of the stage at which it is admitted.

Considerations such as the foregoing largely restrict the extent to which the full benefit of C.E. can be obtained in the main turbines, even in cases where several alternative connections are provided for the admission of the exhaust steam.

(3) **The C.E. Pressure.**—The pressure in the exhaust system not only largely determines the steam consumption per B.H.P. of the auxiliary engines of any installation, but also affects the amount of useful work that can be done subsequently by this steam in the main turbines.

In a given installation the absolute value of the exhaust pressure will vary largely with the *number* of auxiliary engines in use as well as with the power output of the machinery and the feed heater surface in use. This is well shown in Fig. III on p. 69 of Papers, No. X.

The operating engineer can, however, evidently exercise some control over the pressure of the exhaust steam by throttling the pipe line through which it is finally passed from the C.E. system. If by this means he raises the pressure at a particular power, then the total consumption of auxiliary steam will be increased and more heat passed to the main turbines. The change in overall heat consumption due to varying C.E. pressure is almost negligible at the highest powers, although the effect is appreciable at low powers.

(4) **The Design of the Auxiliary Engines** will evidently affect the relative quantities of main and auxiliary steam available under any

particular condition, and thus the absolute values of the economy to be expected by use of the latter in the turbines will be altered correspondingly.

The design of the main turbines may also have an appreciable bearing on this question, especially in cases where they are arranged to make good use of high pressure steam under lower power conditions. Generally the less the economy of the turbines, the greater the percentage saving due to the use of C.E. in the main engines.

As a general rule it may be taken that when the auxiliary exhaust is used in the main turbines, some 83 to 84 per cent. of its heat will be rejected to the condenser; that is, judged solely as a means of exhaust disposal, the system has an efficiency of only about 16 to 17 per cent. under the most favourable conditions.

(*c*) **Use of the Auxiliary Exhaust in Evaporators.**—The major part of the heat supplied to the evaporators in the form of primary steam is either rejected to the distiller circulating water, or is discharged overboard in the brine. The remainder mainly appears in the coil drain or in the gained water, a comparatively small percentage being lost by radiation, leakage, etc. The cost of operating the brine, feed and fresh water pumps is a legitimate charge upon the exhaust when considering the evaporators solely as a means of disposing of the heat in the C.E. As, however, this is relatively small, it has not been considered in what follows.

The possible means of saving heat in evaporators have been briefly referred to in an article in Papers No. X (p. 96), whence it appears that only the coil drain is used in practice to effect savings of this nature, the water being either passed through a feed heater or else directed to the feed tank. The evaporator feed water is now generally heated by the secondary steam, but although this increases the output of the plant per pound of primary steam, it does not decrease the percentage loss of heat. This may be readily seen from consideration of the fact that all the heat in the primary steam is lost with the exception of that part of the heat in the coil drain which is actually returned to the boiler feed system. In this latter connection it may be observed that when a closed feed system is in actual operation, there is no thermal advantage to be gained by discharging the coil drains to the feed tanks, for the reasons mentioned earlier in this article. The following table gives a heat balance for a typical evaporating plant working in single effect (*i.e.*, simple evaporators) :—

	Percentage of heat supplied to coils.
(*a*) Coil Drain	15·0
(*b*) Distiller Circulating Discharge	68·5
(*c*) Brine Discharge	6·0
(*d*) In gained water	5·5
(*e*) By radiation and leakage	5·0

It is evident from this that if all the heat in the coil drain is saved, then single effect evaporators have an efficiency of about 15 per cent., regarded solely as a means of exhaust disposal. The foregoing percentages are reckoned on the total heat per lb. of the primary steam, above a datum of 32° F.

Summary.—The three systems discussed are thus capable of saving (*a*) 90 per cent., (*b*) 16 per cent., and (*c*) 15 per cent. respectively of the heat in the exhaust steam, and the fuel consumption of the whole plant will be proportionately lower, compared with the case where the exhaust is condensed.

It is necessary, however, to take into account the value of the fresh water produced by method (*c*), as this important by-product is the decisive factor in determining which system to employ in actual practice. There are two points which must be appreciated in this connection, namely, that the *heat* consumption of the evaporating plant when producing water at a given rate is unaffected by the source of the primary steam (*i.e.*, whether C.E. or live steam); and secondly, that no existing process of exhaust disposal operates without *some* loss.

It follows from the foregoing that, if the evaporator steam is taken from the C.E., the total loss of heat from the exhaust disposal system (other than the evaporators) will be reduced; while the heat expenditure for distilling will be no greater than if live steam were used for this purpose. To make the matter clear let it be assumed that 100 heat units are available in the auxiliary exhaust steam; that this may be disposed of at the "efficiencies" already quoted; and that in order to supply the required quantity of distilled water, 20 heat units must be taken from the evaporator coil steam. If live steam is used in the evaporators the total heat consumption will be $20 + \cdot 1 \times 100 = 30$, *or* $20 + \cdot 84 \times 100 = 104$ when passing the C.E. to the feed heaters or to the turbines respectively.

On the other hand, if C.E. is used in the evaporators, the heat consumption will be $20 + \cdot 1\ (100\text{-}20) = 28$, *or* $20 + \cdot 84\ (100\text{-}20) = 87 \cdot 2$ when passing the surplus C.E. (not required for distilling) to the feed heaters or to the turbines respectively. These totals are, of course, additional to the heat consumption of the main and auxiliary engines themselves. The figures are merely illustrative, but serve to bring out one further point, namely, that the absolute differences between the various methods will become negligible when the evaporator demand is but a small percentage of the total heat in the auxiliary exhaust—the maximum saving will occur when the whole of the C.E. can be used for distilling.

It will now be evident that if a demand for distilled water exists, it should be satisfied by use of the C.E. steam for that purpose, this being the more economical course, despite the apparently low value of the evaporators as a means of exhaust disposal. Where, however, there is no demand for water, or if this can be purchased from external sources more cheaply than it can be made the exhaust steam should be employed for feed heating.

The figures given for the evaporating plant have been confined to single effect installations and the foregoing comparisons deal only with such units. Compound or double effect systems are now being more generally adopted, and in their case about 30 per cent. of the heat supplied in the primary steam reappears in the coil drain. Rather more than half of the *gained water* appears in the coil drain of the secondary evaporator, and if the heat in this is not returned to the feed system there is no practical difference in *thermal* efficiency between working in single and in double effect; the latter system, of course, produces more water per pound of coil steam than is the case when working in single effect.