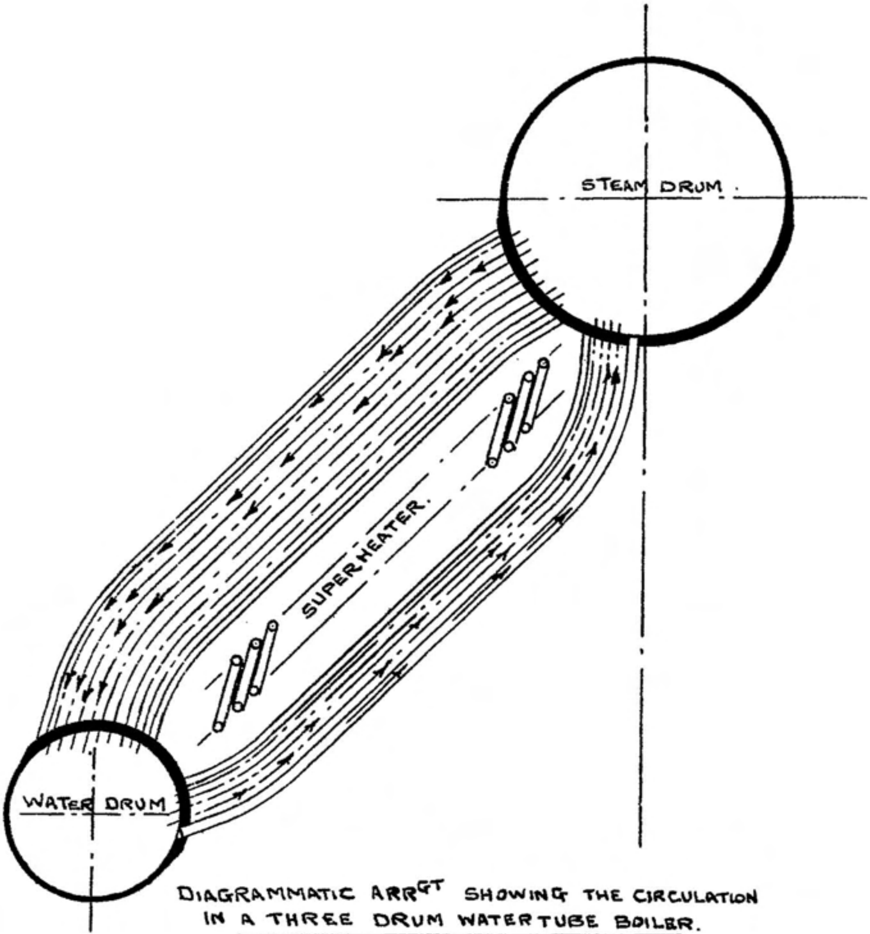
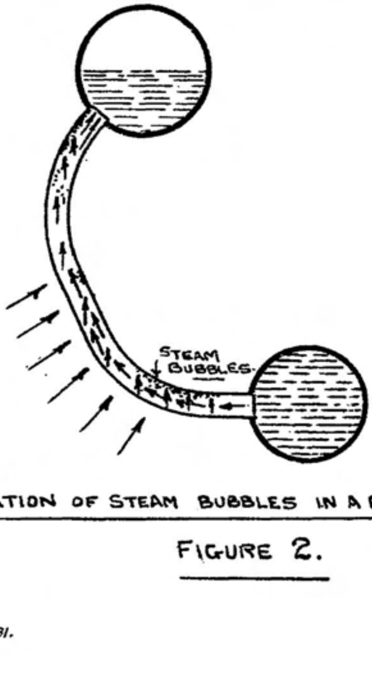


DIAGRAMMATIC ARR^{GT} SHOWING THE CIRCULATION IN A THREE DRUM WATERTUBE BOILER.

FIGURE 1.



FORMATION OF STEAM BUBBLES IN A BENT TUBE.

FIGURE 2.

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2

FEED WATER CIRCULATION IN HIGH-PRESSURE BOILERS.

Feed water circulation.

The circulation of the feed water across the heating surfaces of all the usual types of boiler is obtained and maintained solely by differences in temperature. Fig. 1 shows schematically, the circulation in the case of a three-drum water-tube boiler. Any steam bubbles formed in the front bundle of tubes must be immediately carried into the steam drum by means of the circulating water stream, and at the same time water passes down the rear bundle of tubes into the water pocket. Should steam be formed in the downcast tubes, and this cannot be avoided with certainty, the circulation will be disturbed and the front tubes, which are exposed to very considerable heating, may be burned through.

The tubes should not be made straight and steep all the way, but are preferably considerably bent, as by this means the bending stresses on the tubes themselves are reduced, while the axial thrust on the rolled ends is relieved. These loads are of course due to the differential expansion of the various tubes, which do not necessary transmit equal quantities of heat, even when situated in similar longitudinal rows in the nest: in fact, the probability is that the rate of heat transmission varies appreciably (even considerably) from tube to tube, and thus the temperature of the tube walls and the consequent expansions will differ in like manner. Any considerable bending of the tubes makes more difficult the desired free release of the steam bubbles, which tend to be driven against the upper wall of the tube, forming nests that are carried along by the circulating water stream with increasing difficulty as the tube is made more bent (Fig. 2).

The risk of damage to the tube from such collections of bubbles becomes increasingly serious as the inclination of the tubes approaches the horizontal, and in general the diameter of the tubes must be increased as the slope is reduced. In the Yarrow type, the tube inclination does not usually exceed 50° to the vertical, and tubes of 1¾-in. diameter can be safely used at high rates of forcing for even the fire rows in such boilers.

On the other hand, in boilers of the Babcock & Wilcox type, where the usual slope is only about 15° to the horizontal, it is found essential to provide fire row tubes of some 4 inches diameter, and even these cannot safely be forced to the same extent as in the Yarrow type.

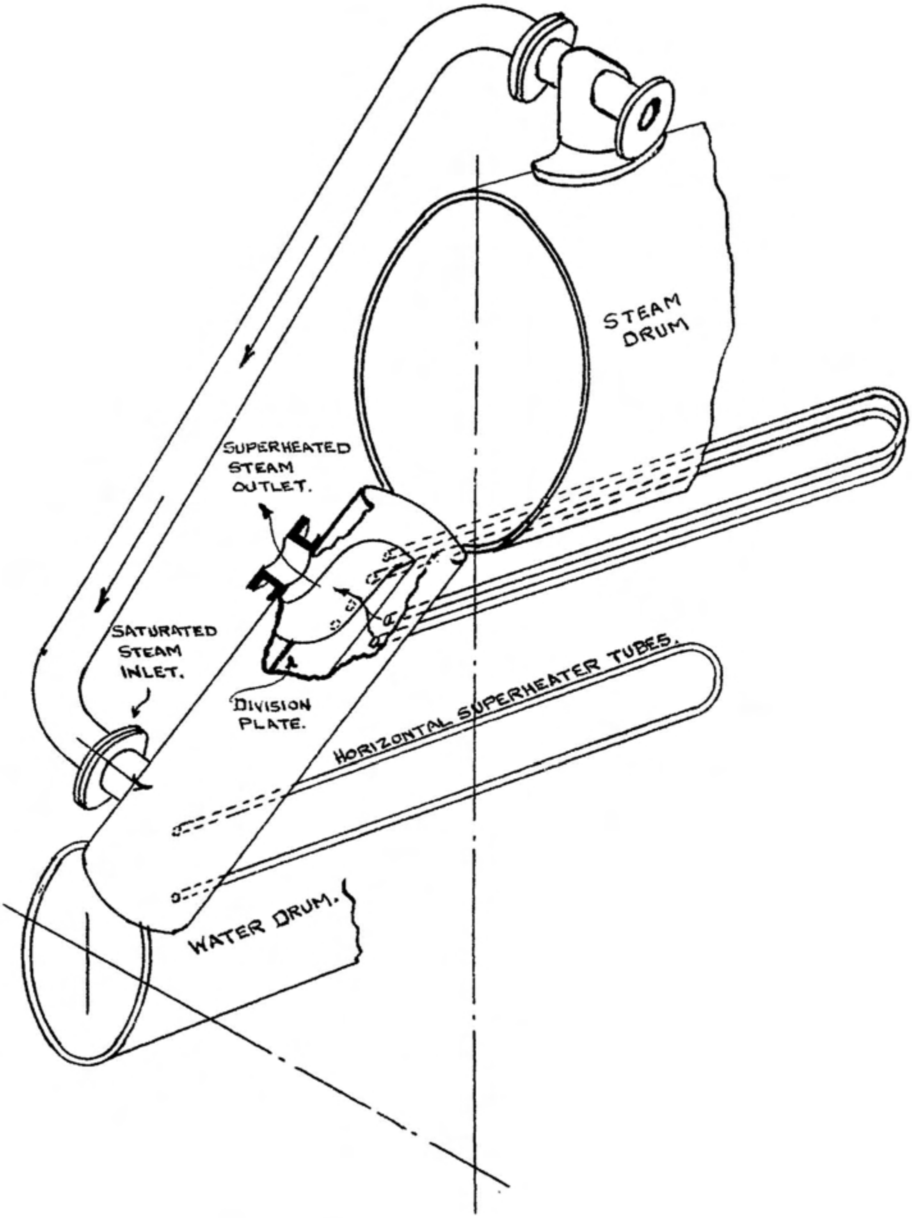
Generally speaking, experience seems to indicate that whenever the slope of a boiler tube becomes less than a certain limit, determined mainly by the existing rate of heat transmission and by the internal diameter of the tube, overheating is to be expected. There is some evidence to show that in such cases steam bubbles obstruct the circulation. One example of such an action was to be seen in boilers of the Thornycroft (Daring) type; here a number of the tubes were considerably bent in order to enter the steam drum, and part of the length was not only horizontal, but actually above the normal water level: frequent burning out of these tubes at the horizontal part was experienced.

Another case which may also be ascribed to the same cause arises in those types of superheaters in which the tubes are horizontal (or nearly so), and where the saturated steam is supplied to the lower tubes first, subsequently passing in series through the remainder of the nest (Fig. 3). Serious distortion of these lower tubes may be experienced, and it appears probable that this is due to the water of priming becoming collected in the horizontal portions: this water, which has little or no tendency to circulate through the tubes, is evaporated, and, forming steam bubbles, lays bare the tube walls locally; it is even possible that the water is blown completely out of the tubes.

It is frequently stated that if generating tubes are approximately vertical, there is more risk of burning out than in inclined tubes. This may be due to the formation of a steam film all round the inner circumference of vertical tubes, whereas in inclined tubes the most highly-heated surface (the lower one) is automatically freed from steam which rises and collects on the upper, relatively cool, surface. It should be noted, however, that if the inclined tubes are heated on their upper, instead of on the lower surfaces, they are more prone to overheating than are vertical ones.

It is evident that the steam bubbles become smaller and more dense as the pressure of generation is raised, and thus the motive power responsible for the water circulation (*i.e.*, the difference in the densities of the fluids in the downcomers and up-casts) becomes correspondingly less. The dangers and difficulties associated with inadequate circulation thus become greater with increase of pressure, so that all conditions must be avoided, which in the case of low pressure boilers give rise to undesirable results and to damage. The most important is to avoid deposits of scale, etc., on the heating surfaces, and thus the purity of the feed water must be even more scrupulously maintained than is usually the case.

The use of large tubes is to be recommended from the point of view of reducing the resistances in the path of the circulating feed water; such a course, however, not only means thick walls, which are not conducive to heat flow, but also makes rolling of the tube ends a more difficult operation. It is worthy of remark that the major part of the resistance in the circulation circuit is probably due to the "entrance" and "exit" losses to the tubes, and that the frictional losses in the tubes themselves may be relatively unimportant.



U - TUBE SUPERHEATER.

FIGURE 3.

P3926,

It is the general practice, mainly on account of the foregoing factors, to use relatively small tubes in H.P. boilers. These are, of course, easier to bend, but, in addition to any increased resistance due to their use, they have the disadvantage that, in order to obtain a given surface, either their number or length must be increased as compared with large tubes. An increase in numbers makes it more difficult to obtain uniform distribution of the feed water in the individual tubes, while the length is strictly limited by the necessity for providing at the upper ends of the tubes a sufficient flow of water and steam to remove the heat as fast as it is supplied. The composition of the fluid in the upcast tubes is very uncertain, but it must consist of a mixture of steam bubbles and water: if the steam content is excessive, burning of the wall will occur. In the downcasts, which may comprise external downcomers as well as the rear series of tubes, there should be little or no formation of steam, a state which can only be assurred by the provision of external downcomers; these fittings are uneconomical as regards weight, since they add to the length of the steam and water drums, without at the same time contributing to the heating surface.

Investigations regarding the speed of circulation in a boiler of the 3-drum type has shown that, as might be expected, this is somewhat indefinite in certain rows of tubes; the tubes exposed to the fire and those immediately adjacent act as upcasts, while the outer rows perform the functions of downcasts: somewhere in the region between these extremes the direction of the circulating stream is uncertain, and the position of this zone varies with the rate of evaporation. This explains why tubes in the third and fourth rows from the fire are not infrequently severely overheated at moderate rates of forcing, although both they and the more highly heat-stressed fire-row tubes in the same boiler successfully withstand the more arduous furnace conditions and higher gas temperatures which obtain at full power.

The difficulties met in the older forms of boiler apply with particular force to the 2-drum type, which is at present enjoying some favour for high-pressure work, in view of the relatively low weight and cost consequent upon the small number of drums. The principal difficulty is that of arranging sufficient heating surface in conjunction with the size of drum usually available in practice, this being determined by the fact that if joints are to be avoided the drum has to be constructed from a single ingot. This factor means that the tubes have usually to be considerably bent, in order to avoid unduly increasing the height of the unit; as has already been pointed out such a course is undesirable from the aspect of good circulation, and the fire row tubes are thus very sensitive to the slightest disturbance, especially if highly forced.

Boilers of this type are liable to fluctuations of the water level in the steam drum, because at high outputs the water surface becomes inclined from a high point above the fire rows to a low one above the rear tubes, which may, in fact, become actually starved of water under such conditions. It is probable that similar inclinations are experienced in the 3-drum type, but in this case the high point is at the centre of the drum, with low ones on either side, and the danger of starving the wing rows is manifestly less.

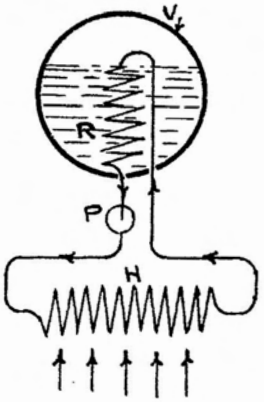
Summing up then, it may be stated that the main disadvantage of the existing types of boiler lies in the uncontrolled circulation, and this feature limits the rate at which changes of output can be made. High-pressure boilers inherently are likely to have less definite circulation than their low-pressure counterparts. The cost and weight of high-pressure boilers are largely determined by the number and dimensions of the necessary steam and water collectors. We, therefore, now have two features that must be kept before us in attempting to produce boilers for generating high-pressure steam, namely, that adequate circulation must be provided, if possible under complete control, and that the number and size of the drum elements must be reduced to a minimum. Let us consider some of the designs that have been produced with the object of meeting either or both of these requirements.

Boilers employing forced circulation of a "heat carrier."

Attempts have been made to transfer the heat directly to the water by the forced circulation of some heat-carrying agent by means of a pump. Fig. 4 shows the general type of plant used in which the carrier is forcibly circulated through a heater H, while the subsequent transference of heat from the carrier to the water is effected in a boiler drum by means of the coil R. Various substances have been proposed as suitable thermal carriers, *e.g.*, mercury, molten metals, naphthalene and oil. This process must not be confused with the so-called Binary system (as in the Mercury or Di-methylethylene turbines), where the primary fluid, say, the mercury, is evaporated in a boiler, the vapour being then used to produce power in a suitable prime mover, subsequently being condensed in a second heat exchanger, where its latent heat generates steam, which is finally employed in a normal power circuit. Such binary systems have been devised solely with a view to improving economy and are not in any way concerned with questions of steam generation.

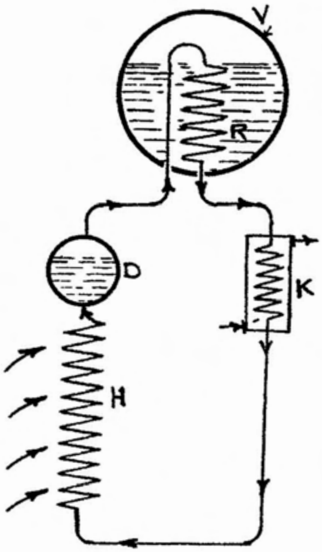
None of these types has as yet attained any significance, principally owing to difficulties associated with the properties of the "carrier" at various temperatures. Trouble has been experienced, too, on account of incrustation and the separation of bubbles or impurities, all of which lead to rapid deterioration of the heating surface.

Water and steam may, however, be used as thermal carriers, and in such cases many of the foregoing disadvantages disappear, although they may be replaced by other undesirable features. The ordinary sea-water evaporator is a special example of this class,



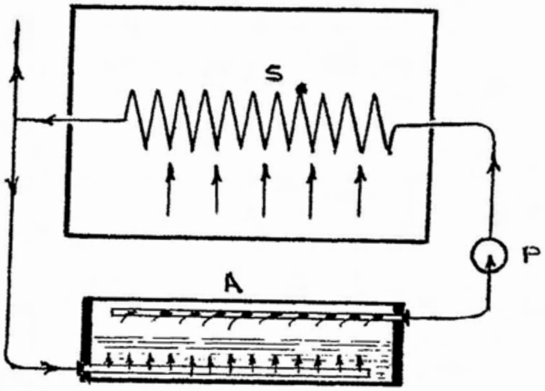
FORCED CIRCULATION OF A HEAT CARRIER

FIGURE 4.



DIAGRAMMATIC ARRANGEMENT OF A SCHMIDT-HARTMANN BOILER.

FIGURE 5.



DIAGRAMMATIC ARRANGEMENT OF A LÖFFLER BOILER.

FIGURE 6.

representing a case in which the direct application of the heat of a flame would be likely to cause excessively rapid deterioration of the heating surface, owing to the speed with which incrustation normally proceeds: further, the use of steam as a heating agent offers the possibility of economically disposing of otherwise wasted heat.

In considering heat interchangers of this type, it is well to note that where vapours of the same material act on both sides of the heating surface, a sufficiently high-pressure difference must be maintained if the extent and cost of the apparatus are to be kept within reasonable limits.

Schmidt-Hartmann boiler.

This is a type using distilled water as the circulating medium, no forced circulation being employed. The arrangement may be gathered from Fig. 5, whence it will be seen that circulation is obtained by the difference in density between the water in the rising and falling legs; the natural effect is improved by the cooler K in the downcast, this apparatus being used as a feed heater. The heating or carrier steam is produced in the coil H by the action of the fire, is separated in the steam separator D, and finally, by condensation in the heat exchanger R, its heat is used to generate the working steam in V.

The sole advantage of this type lies in the fact that an extremely pure water supply may be used in the primary circuit, containing the surfaces exposed to the heat of the fire, while the purity of the water used for forming the working steam is of minor importance: the safety of the main evaporating tubes is thus greater than would be the case if they were supplied with an impure feed.

The water circulation is, however, no better than in normal boilers (except so far as it is improved by K), while the complication and, therefore, the cost are considerably increased It has been found also that the pressure difference necessary to secure reasonable rates of transmission increases very rapidly as the secondary steam pressure is raised, and thus the weight of the primary system tends to become excessive if the boiler is used for high operational pressures. It would be necessary to watch two water levels, as the coil in the secondary evaporator V must be kept well covered if the desired output is to be realised: it is probable that the water level in D would be subject to violent fluctuations when the rate of steaming is considerably changed, and it might even be necessary to make provision for releasing some of the water from the primary system at high outputs, while leakages from this circuit would have to be made up by a special pump.

Löffler boiler.

This type of boiler uses steam as a carrier, which is forcibly circulated by means of a pump. Fig. 6 shows the general arrangement, which is as follows. A steam evaporator A contains both water and steam, which latter is circulated by the pump P through the superheating coils S, where heat is taken up from the fire—in practice these coils are arranged in the furnace walls, being heated by radiation. The major portion of this superheated steam is then blown into the evaporator A where it generates fresh steam : the remainder of the superheated steam is employed directly for power production. It may be well to note at this point that " radiation " superheaters usually require to be protected to some extent from the excessive heat to which they are exposed, this being effected by covering them with a thin layer of some refractory or by securing heavy cast-iron blocks to their exposed surfaces. Such safeguards are not necessary if the rate of forcing is low or if the velocity of flow of the steam through the tubes is so great that a high rate of heat transmission can be accommodated by the steam : this latter alternative has its limits, and, of course, involves a very heavy drop of pressure through the superheating elements. In normal boilers radiation superheaters introduce difficulties owing to the fact that the potential rate of heat transmission in the furnace does not fall off proportionately to the lowered evaporation that follows a reduction in the fuel supply to the boiler—in other words, the steam velocity through the tubes becomes less under such conditions, while at the same time the flame is capable of transmitting almost the same quantity of heat as at high outputs : the lowered steam velocity means that less heat can be taken from the tube wall by the steam in unit time, and thus the temperature of the metal rises with a grave risk of ultimate failure. Such troubles as these should not arise where the circulation of the steam is definitely assured and controlled, as in the Lōffler boiler, but in such cases it might conceivably be necessary to circulate more steam than could be usefully employed, discharging the surplus to some convenient but wasteful " sink."

Boilers of the Lōffler type have been built, and after successful experience with an experimental plant, working at about 1,450 lbs. and extending over several years, a 2,000 K.W. installation (with reciprocating engines) has been put into commercial operation in Germany where it is reported to have given over 12 months' satisfactory service generating steam at 1,700 lbs. superheated to 900° F. A thermal efficiency of 30 per cent. is claimed for this plant, that is about equal to the best Diesel engines, but with a much lower cost in fuel as coal is used instead of oil.

The boiler is set in operation by filling the steam space with low-pressure steam from any available exterior source. The circulating pump is set going and fires are lit to heat up the superheater, the connections to the power line being shut off during the process of raising steam. The temperature and pressure of the steam in the evaporator—superheater system is thus gradually increased till the desired operational condition is reached. It takes about one hour to raise the pressure from 200 lbs. to 450 lbs., but the rate of rise above this latter point is very rapid. In cases where H.P. steam is available, from other boilers in an installation, the lighting up of additional units can be achieved in a very few minutes by flooding with steam at operational pressure.

It is interesting to note that the Löffler system is essentially a high-pressure process, and owing to the power required to operate the steam circulating pump cannot be economically carried out at pressures below about 750 lbs. The pumping power is, of course, given by the product of the volume of steam circulated and of the pressure difference across the superheater. Owing to the relatively rapid increase in specific volume as the pressure is reduced from (say) 1,700 lbs. to more normal values, the pressure difference required to maintain the minimum acceptable speed of steam flow through the superheater tubes. becomes greatly increased. The result of these two factors varying in the same direction is greatly augmented in their product, representing the power for the pump. It may be shown that at pressures up to about 300 lbs. the circulating pump requires more power than can be obtained from the steam in the boiler itself: at 600 lbs. the pump uses over 20 per cent. of the power generated, and it is only at 1,200 lbs. that the power for circulation becomes less than 5 per cent. of the total generated. It is to be noted that the power required for the feed pumps increases very considerably as these high pressures are reached.

No troubles have been reported with the steam circulating pumps, which only work against the pressure difference corresponding to the resistance to the flow of steam through the superheater tubes, etc. The experimental pump was of the plunger type, but it is understood that centrifugal units are now employed.

One of the great advantages claimed for this type of boiler is that any incrustation is deposited on the sides of the evaporator shell, where its presence may even be beneficial in preventing loss of heat, instead of upon heating surfaces where it would be a source of danger.

" Flash " Boilers.

These are, in effect coiled tubes through which a forced circulation is obtained by means of the feed pump, neither steam nor water reservoirs being provided. It is evident that such units must be extremely sensitive to the rate of feed supply, and, while they can be made to operate successfully under conditions of steady steaming, they are obviously unsuitable for marine installations where rapid changes of output are encountered.

Benson Boiler.

This type of boiler operates at a pressure exceeding that corresponding to the critical pressure for steam. The change from water to steam takes place therefore without the evolution of bubbles, etc., being in fact a smooth continuous process. It was hoped that this might avoid the difficulties referred to above in connection with " Flash " boilers, to which type the Benson boiler belongs; unfortunately, this hope has not, as yet, been realised. A full-scale unit of this type is operating at the Siemens-Schuckert Works in Germany, and, although a measure of success has been obtained as regards the anticipated economy, there appears to be little doubt that difficulties have been encountered in maintaining the circulation when unsteady demands for steam prevail. The boiler appears to provide a reliable method of producing high-pressure steam *if* a steady production of steam is required, and provided that very careful control of the heating and of the circulation of the purest possible feed water is effected.