The general object of the present invention is to provide an improved method of and apparatus for washing wet steam to reduce the amount of solids carried by the steam. While not restricted to such use, the invention was primarily devised and is especially adapted for use in treating the steam generated in power plant boilers operating at relatively high ratings and supplied with boiler feed water containing impurities.

In the operation of such a power plant boiler, the bulk of the impurities carried into the boiler with the feed water, does not pass out of the boiler with the steam discharged, and, in consequence, the water within the boiler normally contains a much higher percentage of impurities than does the boiler feed water. For example, the impurities in water fed to power plant boilers seldom amount to more than about 200 parts of solids per million parts of water, while it is customary to permit an impurities concentration in the boiler as high as 2000 parts of solids per million parts of water. The concentration of impurities in the boiler water is regulated by the blow down discharge of 10% or so of the water supplied to the boiler. The steam liberated in a power plant boiler operated at high rating invariably carries entrained water which has the same impurities content as the boiler water not entrained.

Solids carried out of the boiler by the steam have an injurious effect on apparatus in which the steam is subsequently treated or used, and particularly on superheaters and turbines. It is generally recognized, for example, that if the solids content of the steam amounts to as much as one part per thousand of solids per million parts of the condensate formed by condensing the steam, the solids may deposit in a superheater and cause the super heater tubes to burn out, and may erode out the blades, and deposit on the blades and thereby lower the efficiency and disturb the balance of a steam turbine in which the steam may be used.

The injurious effects of a considerable solids content in water entrained by the steam have long been generally recognized and have led to a considerable use of one or another of various arrangements for washing impurities out of the steam by mixing boiler feed water with the boiler water entrained in the steam. Such dilution of the impurities in the water entrained in the steam is effected in some cases within the boiler drum from which the steam generated is withdrawn from the boiler, and in other cases is effected in special apparatus external to the boiler. In general, the steam washing operation has been effected by bringing the steam into intimate contact with the boiler feed water in one or the other or both of two ways; namely, by causing the steam to bubble through a body of boiler feed water, or by bringing the steam into contact with the boiler feed water which is in a finely subdivided form, and particularly by causing the steam to move at a relatively slow velocity through a spray or curtain, of finely divided boiler feed water.

In washing steam in accordance with the present invention, the solids content of the water entrained in the steam is reduced in successive stages, in each of which diluting water in finely divided form is first added to the steam, and thereafter water is separated from the steam to reduce the moisture content of the latter. In the preferred form of the invention, the diluent water is sprayed into admixture with the steam in each treatment stage while the steam is moving at a relatively high velocity through a restricted flow path portion of the washing apparatus into a less restricted portion of the flow path where water is separated from the steam.

The multistage treatment of the water has the fundamental advantage of requiring substantially less diluent, or waste, water than is required for a similar elimination of impurities in a single stage treatment. Thus, for example, it is theoretically possible in washing steam containing one half per cent of water having an impurities content containing 2000 parts of solids per million parts of water, with wash water having an impurities content of 200 parts of solids per million parts of water to eliminate as large a portion of the impurities in a two stage treatment in which the steam is washed with about 7% of the boiler feed water in each stage, as can be eliminated by using all the boiler feed water as wash water in a single stage steam washing operation.

The reduction in the amount of wash water required, which is characteristic of the invention, permits of a reduction in the bulk and cost of the washing apparatus, and makes it practically possible to maintain operating conditions which of themselves contribute to a further reduction in the bulk and cost of the apparatus described.

A reduction in the amount of wash water required makes it practically possible and desirable to use condensate or other wash water purer than the boiler feed water, in some cases in which it would not be feasible to use the purer water.
If a larger amount of wash water were required. An increase in its purity increases the washing efficiency of the wash water, and thus tends, of itself, to a reduction in the amount of wash water required.

The reduction in the amount of wash water made possible by the use of the present invention makes it practically feasible and desirable in some cases to provide special pumping apparatus for supplying the wash water at a suitably high pressure to the washing apparatus, or for passing the drainage, mainly wash water, to the boiler from the washer which may then be located below the boiler water level. An increase in the pressure at which the wash water is supplied to the spraying nozzles of the washer permits of a finer subdivision and dispersion of the water sprayed into the steam, and thereby increases the efficiency of mixture of the wash water with the water previously entrained in the steam, and such an increase in mixing efficiency directly increases the amount of impurities which can be eliminated from the steam by a given amount of wash water.

A further advantage of the reduction in the amount of wash water needed is that the correspondingly small amount of water draining from the washing apparatus may be wasted, or used less efficiently than when it is returned directly to the boiler, without significant detriment to the overall efficiency of the power plant, and with the advantage of making it unnecessary to elevate the washing apparatus so that it may drain directly into the boiler.

While it is theoretically possible to obtain an advantage by further increasing the number of steam washing stages, in ordinary practice the advantage obtained by using more than two stages, will not be sufficient to justify the small increase in apparatus cost required for the use of more than two stages.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages, and specific objects attained with its use, reference should be had to the accompanying drawing and descriptive matter in which I have illustrated and described preferred embodiments of the invention.

Of the drawing:

Fig. 1 is a diagrammatic representation of one embodiment of the invention;

Fig. 2 is a vertical section through the steam washer shown in Fig. 2;

Fig. 3 is a section on the line 3—3 of Fig. 2;

and

Fig. 4 is a diagrammatic showing of the second embodiment of the invention.

In the drawing and referring first to the form of the invention shown in Figs. 1, 2 and 3, A represents a steam generating boiler discharging saturated steam through a steam pipe A', and receiving feed water through the feed water supply pipe A2. The invention may be used with boilers of all types, the boiler A conventionally illustrated by way of example in Fig. 1, being of a well known type, comprising a lower water drum A3, connected by banks of uprighting tubes to the front and rear upper steam and water drums A4 and A5, which are connected by the usual steam circulator pipes. The steam discharge and feed water pipes, A' and A2 are shown as connected to the rear drum A5. As shown, also, the boiler is provided with a steam superheater A6.

A steam washer B constructed and arranged in accordance with the present invention, has its steam inlet B' connected to the outlet end of the boiler steam pipe A', and has its steam outlet B' connected by a pipe B2 to the inlet of the superheater A6. In the preferred form shown, the steam inlet pipe B3 is a horizontal tank having its interior divided by partitions into an inlet chamber C at one end of the tank, to which the steam inlet B' opens, an outlet chamber F at the other end of the tank, from which the steam outlet B2 opens, and two intermediate chambers G and F. A transverse partition C between the chambers C and F, except for a communicating passage formed by the bore of a mixing nozzle H which extends axially through the partition C. The chambers F and G are separated by a transverse partition C, except for a communicating passage formed by the bore of a mixing nozzle H extending through the partition C. The chambers G and E are separated by a transverse partition C, except for a communicating passage formed by the central opening C9 in the partition and by the bore of an axially extending pipe C' supported by the partition C' at its chamber G side. As shown, the adjacent ends of the pipe C' and nozzle I are separated by a distance substantially greater than their internal diameter. As shown, the partition C, C' and C' are sheet metal discs welded at their peripheral edges to the tank body of the washer.

The steam passing from the boiler A to the washer inlet B', is discharged into the chamber C in an axial jet which impinges against a liquid separating baffle C' interposed between the inlet B' and outlet nozzle H. In the advantageous forms shown, the baffle C' comprises a plate slightly inclined to the vertical, and welded at its upper and lower ends to the wall of the washer tank, and of a width somewhat less than the internal diameter of the tank, so as to provide a steam port between each side edge of the baffle and the adjacent portion of the tank wall. At its side adjacent the inlet B', the baffle C' is provided with a plurality of longitudinal ribs C'. In the chamber E, another liquid separating plate D is interposed between the outlet end of the nozzle C' and the washer steam outlet B2. The baffle has ribs D' at its inlet side and may be of the same width as and otherwise the same as the ribs C', but as shown is vertical. Steam passing through the nozzles H and I is subjected to the action of wash water sprays discharged into the inlet ends of the nozzles H and I, by axially disposed water discharge nozzles K and K'. Advantageously, and as shown, each of the nozzles H and I is adapted to act as a centrifugal separator of the water and steam passing through it. To this end, a spiral vane h is mounted in the nozzle H, and a spiral vane i is mounted in the nozzle I. As shown each of said vanes is in the form of a metal strip twisted to form about an axis that is helical about the axis of the water pipe, and extends along about the final two thirds or three quarters of the length of the nozzle. Each of the nozzles H and I with its spiral vane, is thus adapted to give the water an entraining movement added to the steam entering the nozzle, a tangential movement. It leaves the nozzle, whereby much of the water is separated from the steam in the chamber into which the nozzle discharges.

Water separating from the steam in the com-
portments C, F and G, passes out of those chambers through their respective downwardly extending drain pipes L', L² and L³, and water separating from the steam in the final washer chamber E, passes away from the latter through one or the other of the drain nozzles C into the drain pipes L' and L² which communicate at their upper ends with the portions of the chamber at opposite sides of the baffle D. The various drains L', L², L³, L⁴ and L⁵ are connected at their lower ends by a horizontal pipe L so as to maintain water sealed communication between the lower ends of the different drain pipes. Water draining out of the washer B through its different drain pipes is returned to the boiler by a return pipe M shown as having one end connected to the lower boiler drum A² and its upper end connected to the drain L, somewhat above the pipe L.

With their lower ends in water sealed communication, the water levels in the pipes L', L², L³, L⁴ and L⁵ will be at progressively increasing heights, since, as a result of friction losses, the steam pressures in the different compartments of the washer will progressively decrease from the inlet compartment E to the outlet compartment B. With the arrangement shown, the water levels in the drain pipes are prevented from becoming unduly low by connecting the upper end of the return pipe M to the drain pipe L at a level sufficiently above the level of the bottom connection pipe L.

Feed water is supplied to the boiler as required through a feed pipe P and boiler feed regulator P'. The latter has one outlet branch pipe P² connected to the boiler water inlet A² and a second outlet branch pipe P³ connected through outlet branches P⁴ and P⁵ to the previously mentioned wash water supply nozzles K and K' in the steam washer. To ensure that a suitable portion of the boiler feed water is delivered to the steam washer nozzles K and K', the branch P⁵ of the boiler feed line leading to the boiler feed water inlet A³ includes a loaded check or pressure valve NF, which will open only when the pressure at its outlet side P⁶ exceeds the pressure at its outlet side by a predetermined amount.

To guard against an objectionable accumulation of water in the chamber D, such as may result from an overload condition, or a failure of the regular drainage system of the washer, I provided a supplementary, or emergency, drain pipe connection O for the chamber E. As shown, the pipe O is connected at its upper end to the drain pipe L⁴ at a level somewhat above the level of the water in the pipe L⁴ under normal operating conditions. The lower end of the drain pipe O is connected to a trap or discharger O', which discharges to waste, or to some suitable receiving space for boiler feed water, or water to be used for some other purpose.

In the normal operation of the apparatus collectively shown by Figs. 1, 2 and 3, a considerable portion of the moisture content of the steam entering the washer through the inlet B is eliminated in the chamber C by the baffle C'. The steam passing through the mixing and separating nozzle I from the chamber C into the chamber F has its moisture content substantially increased by the wash water spray jet discharged by the spray nozzle K. As the steam and water mixture passes from the nozzle H into the chamber F, water is separated from the steam in an amount which is comparable with, and may be equal to, the amount of water discharged by the nozzle K. In passing through the mixing and separating nozzle I, the moisture content of the steam is again increased, and thereafter water is separated from the steam in the chamber G in the same manner, and substantially to the same extent, as in the chamber F. The steam passes from the chamber G through the pipe C⁷ in a high velocity stream which impinges against the ribbed baffle D, with the result of a further reduction in the moisture content of the steam.

The operating results obtained with the apparatus shown in Figs. 1, 2 and 3, are dependent on the size and relative proportions of the washing apparatus, and upon the conditions of operation. With all normal operating conditions, however, it will be possible to obtain as good steam cleaning results by passing a fraction only of the boiler feed water through the nozzles K' and K² of the apparatus, as are obtainable with all of the boiler feed water used as wash water in a single stage washing operation.

Thus, for example, if it be assumed that the solids content in the water entrained in the steam passing from the boiler A, to the washer B, amounts to two thousand parts per million of water, and that one half percent of water is entrained by the steam as it enters each of the mixing nozzles H and G, and that the solids content of the feed water is two hundred parts per million of water, and that all of the wash water and all of the entrained water are uniformly mixed in the passage of the steam through each of the mixing chambers H and I, and that the steam leaving the washer entrains one fifth of one percent of water, and that seven percent of the boiler feed water is discharged by each of the spray nozzles K and K², then, as can be shown by simple arithmetic, the steam leaving the washer will carry less than one half, approximately .416, of a part of solids per million parts of steam. That solids content is a trifle less than will be carried by steam subjected to a single stage washing operation in which all of the boiler feed water is used as wash water, if it be assumed that the steam washed entrains one half percent of water containing two thousand parts of solids per million parts of water, and that the feed water carries two hundred parts of solids per million parts of water, and that all of the wash water is uniformly mixed with all of the water entrained by the steam, and that after the single stage washing operation, water is eliminated from the steam to reduce its entrained water content to one fifth of one percent. As can be shown by simple arithmetic, the steam so treated will then carry approximately .418 of a part of solids per million parts of steam.

In practice, the mixing efficiency of the apparatus shown in Figs. 1-3 will not be as good as assumed in the preceding paragraph, so that some of the minute entrained droplets of impure water will not have added to them their proper proportion of the wash water. However, if the assumptions made in the previous paragraph are modified by the assumption that only eighty percent of the entrained water entering each of the mixing nozzles H and G, is therein mixed with its proper proportion of the wash water sprayed into that mixing nozzle, and that twenty percent of the entrained water which the steam carries into each mixing chamber, passes out of the latter without any dilution by the wash water, the spraying of seven percent of the boiler feed water, into each of mixing nozzles H and I, will reduce the solids content of the steam leaving
the washer with a moisture content of one fifth of one percent, to about sixty-three hundredths of a part of solids per million parts of steam.

With an eighty percent mixing efficiency assumption added to the assumptions made in the previous paragraph, the steam subjected to a single stage washing operation in which all the boiler feed water is used and containing one fifth of one percent of moisture, will carry about one and three tenths parts of solids per million parts of steam.

In consequence of pressure losses in the pipe A' and washer B, the steam pressure in the final compartment of the washer B will be less than the boiler steam pressure by an amount which may be as much as five or more pounds under heavy load conditions. With the arrangement shown in Fig. 1, the steam washer B must therefore be located at a level definitely above the boiler water level, to enable the steam washer to drain freely to the boiler. The location of the steam washer B at a level below the boiler water level may be made possible by the provision of a pump for returning drain water from the washer to the boiler, or by the provision of means for delivering the water drained from the washer to some receiver or water using apparatus to which the drainage water may be delivered at a pressure lower than the boiler pressure. It is possible also, to use the general principles of the steam washing apparatus shown in Figs. 1, 2 and 3, in washing steam with pure water and thereby obtaining a washed and dried steam with a smaller solids content than is possible, other things being equal, when impure boiler feed water is used as the wash water.

One plant arrangement or form, in which the relative washer and boiler levels is important, and in which pure wash water is used is diagrammatically illustrated in Fig. 4. The boiler A, washer B, and superheater A', of the plant shown in Fig. 4, may be exactly like the corresponding parts of the plant shown in Fig. 1, and the washer B may be connected to the boiler steam outlet and to the superheater exactly as in Fig. 1. In Fig. 4, however, the main and emergency drain pipes M and O, respectively, are connected to the inlets of steam traps Q and QA, respectively, which have their discharge outlets connected to the inlet of a flash tank R, in which the pressure is below boiler pressure, and may well be but little above atmospheric pressure.

The water discharged by the traps Q and QA, at a temperature but little above the boiler steam temperature, is subjected to a flashing action in the flash tank R, by which a portion, dependent in amount on the boiler and flash tank pressures, is evaporated. The steam thus formed in the flash tank R passes away from the latter through a steam pipe R'. The water not evaporated in the flash tank R is discharged from the latter through a pipe R". In the arrangement shown in Fig. 4, the pipe R" leads to the inlet of a trap QB employed to pass water into an open feed water heater S which may be a demineralizer heater, to which boiler makeup water is passed by the water supply pipe P, through a regulating valve S'. A float S' in the heater S, opens and closes the valve S' as required to maintain under an approximately constant water level in the heater.

In the plant arrangement shown in Fig. 4, the boiler feed water is passed to the boiler by the boiler feed pump V, through a feed line including pipe sections P1, P2, and P3, and the water heating space of a closed water heater W. As much of the condensate formed in the steam space of the heater W and collecting in its hot well or receiver W', as is required for steam washing is passed by a pipe P4 and throttling valve W' to the wash water supply branches P4 and P5 of the washer B. The pump Y may be hand controlled and the valve W' may be a hand adjusted gate valve. As diagrammatically shown, the boiler feed line section P13 includes a boiler feed regulator P' and a non-return valve N'.

Condensate normally accumulates in the hot well or receiver W' in excess of the wash water requirements and overflows through the pipe W5 to the trap QB by which it is discharged into the boiler S. The steam used in heating the boiler feed water in the heaters S and W may be taken from any available source or sources. Advantageously, it includes the flash steam discharged from the flash tank R through the pipe R', and as shown in Fig. 4, the pipe R' delivers the flash steam to the steam inlet of the heater W. The additional steam utilized in the heater W, is bled through a pipe T3 from an intermediate stage of a steam turbine T, and steam bled from a lower pressure stage of that turbine through a pipe T', is employed to heat the water passing through the heater W.

While the arrangement shown in Fig. 4 is somewhat less simple than that shown in Fig. 1, the Fig. 4 arrangement possesses the advantages that it provides, and makes use of, pure wash water, and it permits the washer to be located below the boiler water level, and attains those advantages, moreover, without significant impairment of the high operating efficiency of the arrangement shown in Fig. 1.

While the invention in its broader aspects permits the use of other forms of washing apparatus, the particular form illustrated is compact and efficient, and makes use of water separating and drainage expedients of well tested merit which have been successfully employed in the extensively used receiver separator for eliminating water and air from steam, disclosed in the Fowler Patent 1,669,771, filed Aug. 1, 1921.

While in accordance with the provisions of the statute, I have illustrated and described the best forms of embodiment of my invention now known to me, it will be made in the form of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

Having now described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. In the operation of a steam generating boiler with impure feed water, the method which consists in preheating the boiler feed water with steam whereby condensed and producing condensate separate from the boiler feed water, increasing the pressure of the condensate and spraying it into the steam generated by the boiler, separating water from the steam, and drying the water separated and thereby providing steam used in preheating the boiler feed water.

2. That in an arrangement for a steam generating boiler, of means including a closed water heater for supplying preheated boiler feed water to the boiler, a steam washer through which steam generated in the boiler is passed, means for supplying water preheating steam to said heater and in which water separates from said steam, means
for spraying condensate formed in said heater into the stream passing through the washer, flashing means for flashing water separating from the steam in the washer and means for passing flash steam from said flashing means to said water preheating steam supply means.

3. The combination with a steam generating boiler, of means including a closed water heater for supplying preheated boiler feed water to the boiler, a steam washer through which steam generated in the boiler is passed and in which water separates from said steam, means for supplying water preheating steam to said heater, means for spraying condensate formed in said heater into the steam passing through the washer, flashing means for flashing water separating from the steam in the washer, means for passing flash steam from said flashing means to said water preheating steam supply means and means for adding the unflashed residue of the drainage water to the boiler feed water.

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