This invention relates to high pressure vapor generating superheating units and the pertinent method of vapor generating and superheating. The vapor superheating involved in the invention is such as to effect final vapor temperatures of the order of 1000°F to 1100°F. To effect such high vapor superheat temperatures, furnace gases constituting the heating medium must have temperatures of the highest values within the limits of safe superheater metal temperatures and within the limits of other factors affecting the heat absorption in the superheater.

The vapor generating and superheating unit of the invention involves a fuel fired furnace, and with some fuels at least a portion of the furnace must be operated at temperatures considerably in excess of temperature values which are within the safe range for superheat. Such high temperatures are necessary in some instances for the most efficient and economical use of fuel. Under some conditions as to superheating and fuel firing, it is necessary to reduce the heating gas temperatures between the highest temperature section of the furnace and the gas entry to the superheater, and it has been suggested that such reduction in gas temperatures be attained by subjecting the gases to the cooling effect of the water cooled walls of a large volume furnace, the walls including vapor generating tubes. As the fluid pressures of vapor generating units have steadily increased toward and beyond 2000 p. s. i., it has been more and more appreciated that the costs of such large volume water cooled wall furnaces have grown to such an extent that they constitute a predominant part of the entire cost of the unit. Concomitantly, the ratio of heat absorption in superheating to the heat absorption in vapor generation has increased to such an extent that it has been realized that the large volume water cooled furnaces are not necessary for the generation of the amount of vapor required.

It is one of the facets of the present invention that it involves a vapor generating and superheating unit attaining the desired high temperature superheat and the high temperature furnace operation without the use of an intervening large volume water cooled furnace. The unit of the invention involves means intermediate the high temperature furnace and the superheater for cooling the furnace gases by kinetic action. In one embodiment this cooling zone involves a vortex chamber receiving the gases from a cyclone furnace and mixing the gases with other gases of lower temperature so that the temperature of the mixed gases will not exceed the limits imposed by the superheating.

In another limited aspect of the invention, furnace gases are recirculated from a position beyond at least a part of the superheater, the gases to be recirculated having been substantially cooled before they enter the recirculating system. The latter introduces the lower temperature recirculated gases into a vortex chamber for mixing with the gases directly received from a cyclone burner or furnace. Preferably, the recirculated gases and the unrecirculated gases are introduced peripherally of the vortex chamber in such a manner as to promote a vortical or cyclonic mixing action. Preferably, also the flow of gases into the vortex chamber are regulated by the provision of a plurality of peripheral inlets with separate controls for the gas flow therethrough. By this means or other suitable means, the amount of lower temperature recirculated gases entering the vortex chamber may be controlled in the interests of maintaining the gas temperature at the inlet of the superheater within the necessary limits, and in the interest of maintaining a predetermined vapor superheat temperature over a wide load range.

The pertinent apparatus and method as above outlined are also envisioned as operating advantageously with an ash containing fuel. In this event, the fuel is burned preferably in a cyclone burner or furnace at a temperature above the fusion temperature of the ash. In this cyclone burner or furnace, the cyclonic action promotes complete combustion and promotes such an agglomeration and collection of the ash particles that at least the predominant part thereof may be collected and separated from the gaseous products of combustion, for removal by gravity.

The combustion within the cyclone furnace takes place at such high temperatures that the resulting ash particles are in such condition that they would be apt to deposit in a sticky condition on convection heat exchange surfaces, to the great detriment of the heat absorption rating of those surfaces. Under these conditions, the action of the vortex chamber, with the lower temperature recirculated gases entering therein cools the ash particles remaining in the furnace gases to a suitable degree, before they reach convection heat exchange surfaces such as the superheater. A high percentage of the remaining ash particles are also separated from the gaseous products of combustion as a result of the action of the vortex chamber. This pertinent method of operation and the apparatus for effecting it not only reduce the size and cost of the entire vapor generating and superheating unit, but they also materially increase the availability of the unit and thereby substantially reduce the cost of the resulting power. This increase in availability results from the agglomeration and separation of such a predominant part of the ash particles that the availability of the unit approaches closely to one hundred percent.

Preferably, the cyclone furnace of the invention includes vapor generating tubes which on their furnace sides are covered with high temperature refractory material, thermally and mechanically maintained by spaced metallic extensions in good heat transfer relation and secured to the surfaces of the vapor generating tubes toward the interior of the cyclone. The vortex chamber may also be of similar vapor generating tubes and refractory construction.

The invention also includes means for reception of ash separated centrifugally in the vortex chamber, this means being preferably provided by a baghouse filter. Thus, an intermediate chamber, between the cyclone furnace and the vortex chamber is arranged to receive ash separated in the vortex chamber. In one embodiment of the apparatus the gases from the outlet of the cyclone furnace are directed substantially tangentially of the vortex chamber through an upwardly extending duct, extending from a tubular screen of vapor generating tubes inclined to the horizontal and disposed across the gas outlet of the intermediate chamber. The intermediate chamber has in its bottom a molten slag outlet leading to a slag pit or slag tank, and the cyclone furnace has its longitudinal gas outlet downwardly inclined toward the intermediate chamber so that slag may drain through a slag discharge outlet in the cyclone wall.
flow into the intermediate chamber and be discharged through a slag outlet to that chamber. The cyclone furnace chamber has a gas outlet directed toward an upper wall of the intermediate chamber, this outlet being formed by a division wall extending inwardly from a header screen tubes. They continue as tubes in a rear wall and roof of the intermediate chamber to through tubes in the division wall between the cyclone combustion chamber and the intermediate chamber, through tubes or tubular sections in the discharge throat of the cyclone chamber, through tubes in the floor of the intermediate chamber, tubes in the rear wall of the duct extending toward the vortex chamber, tubes in the circumferential wall of the vortex chamber, tubes in the front wall of said duct, and then through screen tubes connected at their ends to another header. The cyclone furnace is provided with an inlet for the introduction of fuel, such as granular coal, and primary air mixing at high velocity. The cyclone is also provided with appropriate tangentially arranged secondary air ports.

In a preferred embodiment of the invention, the part of the convection section nearest the gas outlet of the vortex chamber is a vapor heater or superheater. The unit may involve both a superheater and a reheater. The vapor heater is followed by a convection vapor generating section, a feed water heater (or economizer), and an air heater, in that order relative to gas flow. In one form of the invention an air compressor and gas recirculating fan are arranged to be driven by a gas turbine and the compressor is arranged to supply combustion air to the cyclone combustion chamber by way of the turbine, preceded by an air heater connected to conduct furnace gases flowing from the vapor generating section.

The means for recirculating gases are arranged preferably to extract gases from a point in the gas flow path beyond the economizer. The gas recirculating fan delivers the recirculated gas to an inlet chamber between the circumferential wall of the vortex chamber and an outer casing so that the gases move around that space in the direction of whirl, and the recirculated gas inlets which may be provided with scoop-like gas directing means extending into the space between the vortex chamber and the casing, are arranged to direct the gases substantially tangentially into the vortex chamber. During the operation of the illustrative apparatus with an ash bearing fuel, ash particles in molten form are deposited on the wall of the intermediate chamber and on the tube screen at the outlet of that chamber. Despite the recirculation of the furnace gases by the wall tubes of the cyclone furnace, and the intermediate chamber and the screen tubes, the gases entering the vortex chamber are still at a high temperature and contain some of the remaining entrained ash particles in molten form. The cooling effect in the vortex chamber promotes the condensation on the remaining suspended ash particles of troublesome vapors which may be contained in the unrecirculated furnace gases, and the flow of recirculated gases is controlled to give such a suitable low temperature of the mixed gases that there is at least an approach by the ash particles to solidification, and an approach by the vapor to condensation and solidification or sublimation into aerosols.

The temperature of the gaseous mixture discharging from the vortex chamber need not be so low as to assure complete solidification or sublimation, provided the temperature of the convection surfaces adjacent the outlet of the vortex chamber is sufficiently low, and provided the temperature of the mixture is also sufficiently low. Freezing of the troublesome constituents of the gases will still occur during their passage through the cool gaseous envelope surrounding the tubes of the convection section. The maximum suitable temperature of the gas mixture passing from the vortex chamber depends upon the nature of the ash in the coal and the temperature of the convection heat exchange surfaces adjacent the vortex chamber outlet.

The rate of gas recirculation depends upon the load, and the gas temperature at the gas inlet of the superheater, and the rate of gas recirculation may be considerably greater than the rate of unrecirculated gas flow from the cyclone with the admission being controlled in known manner by a series of suitable valves located at the superheater and preferably in two superheater sections. Reheat may be controlled by a gas by-pass.

The invention also envisions the provision of a plurality of cyclone furnaces arranged to discharge into the same intermediate chamber leading into a common vortex chamber. The invention will be concisely set forth in the appended claims, but for a complete understanding of the invention, its advantages and its details should be had to the following description which relates to a preferred embodiment of the apparatus shown in the accompanying drawings.

In the drawings:

Fig. 1 is a sectional side elevation of a tubulous steam generator embodying the present invention, taken on the line I—I of Fig. 2 as viewed in the direction indicated by the arrows, showing only those parts adjacent the section line;

Fig. 2 is a sectional plan view taken on the line II—II of Fig. 1, again showing only those parts adjacent the section line;

Fig. 3 is a sectional front elevation taken on the line III—III of Fig. 2;

Fig. 4 is a sectional side elevation taken on the line IV—IV of Fig. 3;

Fig. 5 is a diagram indicating the liquid and vapour flow paths in the generator illustrated in Figs. 1 to 4;

Fig. 6 is a diagram of a gas turbine arrangement which may be used to drive a gas recirculating fan in the steam generator illustrated in Figs. 1 to 5; and

Fig. 7 is a diagram of an illustrative vapor generating and superheating unit.

As indicated in Figs. 1, 2, and 3, a cyclone furnace including a cyclone combustion chamber 1, which may suitably be of a kind described in U. S. Patent 2,357,301, September 5, 1944, with reference to Figs. 3 to 9 thereof, or, horizontally elongated, substantially circular cross-section is fixed by a primary burner 2 arranged coaxially thereto in the outer end wall 3, the burner being of a suitable type for the kind of fuel to be fired, which may be a crushed or granular fuel, such as bituminous or semi-bituminous coal. A stream of primary air and granular coal is delivered at a high pressure through a primary air-coal pipe 4 (see Fig. 3) an involute curved end of which opens tangentially into a lower side portion of burner 2.

From the burner the primary air stream moves onto the frusto-conical end wall of the cyclone combustion chamber where the stream experiences a radial and forward motion after which the whirling stream moves axially of the cyclone combustion chamber in a helical path along and in contact with the circular circumferential wall 5. A whirling stream of tertiary air, directed axially of the burner 2, is provided for suitable means (not shown). An axially elongated port 6 is provided for admitting secondary air to the cyclone combustion chamber 1 at a point angularly spaced approximately 180° from the point of entry of the primary air-fuel stream, the secondary air being delivered to the port through a main air duct 7 having its end section fitting into and opening to the port 6, the velocity of air admission being controlled in known manner by a series
of dampers (not detailed) arranged to maintain the entering secondary air stream at all times along the cyclone circumference.

In operation, the primary air-fuel stream enters the cyclone as a high velocity stream whirling in a clockwise direction, as seen in Fig. 3, with an inner core of tertiary air whirling in the same direction. The fuel-air mixture rapidly ignites and the burning stream flows longitudinally of the cyclone at a high angular velocity in a film or layer following a helical path along and in close contact with the cyclone circumferential wall 5. The secondary air enters at substantially the same velocity and with the same direction of whirl and gradually merges with the burning stream of primary air and fuel. Combustion is substantially completed in the cyclone and the resulting hot gases are discharged through the coaxially arranged rearwardly flaring outlet throat 8.

Hot gases discharged from the cyclone are directed towards an upright rear wall 12 of a downwardly extending auxiliary furnace chamber 13, the lower part of which is provided with a rearward extension 14. The auxiliary furnace chamber has in its floor 15 a molten slag outlet 16. If desired, the tubes 17 past the slag with water and provided with a suitable conveyer (not shown) for removing solidified slag from the tank. The axis of the cyclone is downwardly inclined towards the auxiliary furnace chamber so that slag may drain from the cyclone chamber through the slag discharge outlet 18 in division wall 19 between the two chambers into the auxiliary furnace chamber. Although only one cyclone is shown in the arrangement illustrated, an auxiliary furnace chamber may be adapted to receive the discharges from a plurality of cyclones.

Gases leave the rearward extension 14 through an upwardly extending duct 26 leading to a vortex chamber 25 and in the duct pass over a screen 23 of water cooled tubes covered with refractory material. The vortex chamber 25, cylindrical in form, is arranged above the rearward extension 14 of the auxiliary furnace chamber 13 with its axis horizontal and transverse with respect to the axis of the cyclone furnace 1. The duct 26 is arranged to direct hot gases tangentially to the periphery of the vortex chamber.

One end of the vortex chamber 25 is completely closed by a wall 28, while at the other end it is partially closed by a wall 29, provided with a gas outlet 30 coaxial with the vortex chamber 25, in the form of an inwardly extending throating 31. Convection fluid heating sections of the vapour generator, described in detail below, are arranged in the furnace gas flow path subsequent to the vortex chamber.

The walls of the cyclone 1, the auxiliary furnace chamber 13, the duct 26 and the vortex chamber 25 are lined with steam generating tubes, the tubes in the cyclone, in the auxiliary furnace chamber and in the duct 26 being studded and covered with refractory material 32 in known manner, but the tubes lining the vortex chamber being bare on their inward sides, in the preferred embodiment illustrated, the tubes are arranged for forced circulation but, of course, the tubes may be suitably arranged for natural circulation of the cooling medium.

The following description of these vapour generating tubes will be most easily followed by reference to Figs. 1 and 2 in conjunction with Fig. 5, in which the various blocks denote the heat exchange surfaces associated with the similarly numbered parts of the steam generator. A cylindrical steam and water drum 35 is arranged to one side of and above the vortex chamber 25 with its axis parallel to that of the vortex chamber. Water from the drum 35 is forced by a recirculation pump 36 (indicated in Fig. 5 only) into a header 37, from which tubes 38 extend as tubes of the screen 23. The water flow continues thence through tubes in the rear wall 12 and a roof 39 of the auxiliary furnace chamber 13, tubes in the division wall 19 and in the discharge throat 8 of the cyclone, tubes in the bottom 15 of the auxiliary furnace chamber, tubes in rear wall 40 of the duct 26, tubes in the circumferential wall 41 of the vortex chamber 25, tubes in the front wall 42 of the duct 26 and as further tubes of the screen 23, the tubes being connected at their ends to a second header 43. Water is returned from the header 43 to the steam and water drum 35.

Towards each side of and below the auxiliary furnace chamber 13 are three headers 50a, 50b and 50c and at each side of the auxiliary furnace chamber tubes (not detailed) extending upwardly from header 50a and downwardly to the intermediate header 50b line a part of the auxiliary furnace chamber side wall adjacent the cyclone 1 and a portion of a side wall of the duct 26 leading upwardly to the vortex chamber. Other tubes leading upwardly from the intermediate header 50b and downwardly to the header 50c line the remainder of the side wall of the auxiliary furnace chamber, the remainder of the side wall of the duct 26 and the adjacent side wall of the vortex chamber as indicated at 52 for the wall 29. Some of the latter tubes in the side wall 29 of the vortex chamber 25 included in the inwardly extending throating 31. Water is supplied by the pump 36 to the headers 50a from the drum 35 and steam and water are returned from headers 50c to the drum 35.

Where it has been necessary to provide openings in walls lined with tubes in this manner, this has been achieved in a known manner by bending alternate tubes out of the plane of the adjacent part of the wall, for example as shown for the slag outlet 16 from the auxiliary furnace chamber 13.

The walls of the cyclone 1 are lined with tubes connected at their ends to upper and lower headers 54, 55, respectively, in well known manner, and water is supplied to header 55 by pump 36 and steam and water returned from header 54 to the drum 35.

The convection sections subsequent to the vortex chamber include (see Figs. 2 and 4) a steam superheating section 60, a steam generating section 61 and an economizer section 62, all arranged in a gas tight casing 63 provided internally with baffle walls 64, 65, 66, 67 and 68 which cause hot gases leaving the outlet 30 from the vortex chamber to flow in a sinuous path over the sections 60, 61, 62 in that order. The superheating section 60 is formed by a number of sinuous tubes 70 each of which is connected at its ends to a respective upper and lower outlet headers 71a, 71b arranged with their axes extending vertically within the casing 63 but outside the baffle wall 64. If desired, the section 60 may be in two steam superheating sections, one a live steam superheater and the other a steam reheater. The steam generating section 61 is formed by a number of sinuous tubes each of which is connected at its ends to inlets and outlets headers 73a and 73b respectively, arranged with their axes extending horizontally in a space 74 above a false roof 75 interposed between the convection sections and the roof 63a of the casing 63. The economizer section 62 is similarly formed by tubes 76 connected to headers 77a, 77b.

The sections 60, 61 and 62 are connected into the circulation system of the steam generator as indicated in Fig. 5, water being forced through section 61 by the pump 36, steam passing through the section 60 from the steam space of the drum 35 and going to a point of return pipe 78 and feed water being forced by a feed pump 79 through the economizer section 62 into the drum 35. The casing 63 is formed with a hopper-like bottom part 86, which is divided lengthwise into four sections by the baffle walls 64, 66 and 67, for the collection of ash particles which separate from the gases as they pass over the convection sections 60, 61 and 62. Doors 87 are provided in each of these sections for the periodical removal of ash from the part 86.

Some of the hot gases which have passed over the con-
vection sections 60, 61 and 62 are withdrawn through an opening 90 in the casing side wall 63 and pass through a duct 91 into an air heater 92. Air heater 92 is of the type in which each of a number of tubes 93 is connected at its end to two tube plates 94a, 94b respectively, the tubes and the tube plates being enclosed in a casing 95 which is extended beyond the tube plates to form end chambers 96a, 96b. Duct 91 delivers hot furnace gases to the port of the casing between the tube plates at a region adjacent the tube plate 94a and the hot gases flow transversely over the outside of the tubes 93 towards the tube plates 94a, guided by suitable baffles walls 94c, 94d, 94e and adjacent tube plate 94b are extracted from the casing through a duct 97 by which they are delivered to a chimney 98.

Air drawn in from the atmosphere is delivered by a forced draught fan 100 driven by an electric motor 101 into the end chamber 96b of the air heater 92, passes through the tubes 93 into the end chamber 96a and from thence passes through a duct 102 (see Figure 3) which delivers it to a branch pipe 103 connected to the primary air-coal pipe 4 and to the main air duct 7 associated with the cyclone furnace 1.

The remainder of the hot gases in the casing 63 pass rearwards through the casing 63 through a space 104 between the baffle 65 and the side wall 63b of the casing 63 and through the space 74 towards a space 105 between the baffle 64 and the rear wall 63c of the casing. From this space they pass through a duct 110 to a recirculating fan 111 driven by the electric motor 101. From the fan 111 the hot gases pass through a duct 112 into the interior of a casing 113 which surrounds the vortex chamber 25 and the auxiliary furnace chamber 13, the gases being delivered into the casing 113 by the duct 112 in such a manner as to give the gases an anticlockwise whirl (as seen in Figure 1) in the casing 113 about the vortex chamber 25. The lower wall 112a of the duct 112 extends into the casing 113 and is curved upwardly to meet the outside of the rear wall 40 of duct 26.

The circumferential wall 41 of the vortex chamber 25 is formed with five groups 120a to 120e of openings forming five recirculated gas inlets spaced about the circumference of the wall 41 for the passage into the vortex chamber of gases recirculated to the interior of the casing 113. The openings are formed by displacing alternate tubes lining the wall 41 of the vortex chamber out of the wall, and provided outside the vortex chamber with gas directing means in the form of curved scoop-like hoods 121a to 121e which cause gases passing inward through the openings to enter the vortex chamber tangentially with an anti-clockwise whirl (as seen in Figure 1). Inside each of the hoods 121a to 121e are provided damper regulating means indicated at 122a to 122e; the damper means and the hoods are so arranged as to divide each recirculated gas inlet into sections disposed side by side in alignment axially of the vortex chamber, the sections being provided with separately operable dampers (not detailed). This enables the amount of recirculated gas entering the vortex chamber through each of the gas inlets to be separately controlled, and permits control of the zone in the length of the vortex chamber to which those gases are admitted. Suitable operating means, not detailed, are provided for enabling the damper means to be operated from outside the casing 113.

In operation of the plant described above, combustion is effected under pressure in the cyclone furnace. As is well known, in the operation of such a cyclone furnace, ash in molten form is deposited upon and drained from the walls of the furnace and particles of fuel embedded in the layer of molten ash on the circumferential wall of the furnace and are scrubbed by the circulating gases. Molten ash collecting at the rearward end of the cyclone passes through the slag discharge outlet 18 into the auxiliary furnace chamber 13. Almost all of the ash is collected in molten form in this manner. Further ash in molten form is deposited on the rear wall 12 of the auxiliary furnace chamber and on the tube screen 23, whence it passes onto the floor 15 and is discarded.

Despite cooling of the furnace gases by the wall tubes of the cyclone furnace, the auxiliary furnace chamber and the tubular screen 23, the gases entering the vortex chamber 25 are still at high temperature and the entrained ash particles may be in molten form, whilst the gases may contain troublesome alkalis.

In the mixing zone constituted by the vortex chamber the whirling stream of hot furnace gases is subjected to successive blows of relative cool recirculated gases from the recirculated gas inlets and the high degree of turbulence which occurs ensures a good mixing of the hot and the recirculated gases in the limited space available and attainment of the fresh furnace gases. The amount of recirculated gases which is supplied to the vortex chamber is relatively large; the recirculated gases may have a mass flow rate of 70% of the mass flow rate of the hot gases leaving the cyclone furnace. The requisite amount of recirculated gases will depend upon the obtaining conditions, such as fusion temperature of ash in the coal being burnt, and in a vortex chamber lined with closely spaced tubes as described above, it may be necessary under some conditions to have a much higher mass flow rate of recirculated gases of up to, say, 150% (or higher) of the mass flow rate of hot gases from the cyclone furnace.

The cooling effected in the vortex chamber encourages condensation on the ash particles remaining in suspension in the gases of troublesome vapours which may be contained in the fresh furnace gases and the recirculation of gases is so adjusted to give a suitably low temperature of the mixed gases that there is at least an approach by the ash particles to solidification and by the vapours to condensation and solidification or sublimation into aerosols.

The temperature of the mixture of fresh furnace gases and recirculated gases need not necessarily be so low as to ensure solidification or sublimation, since, provided the temperature of the convection surfaces adjacent the outlet from the vortex chamber is sufficiently low and the temperature of the mixture is also sufficiently low, freezing of the troublesome constituents in the gases will still occur during their passage through the cool envelopes surrounding the outer circumference of the convection sections. The maximum suitable temperature of the gas mixture passing from the vortex chamber depends, therefore, upon the nature of the ash in the coal being consumed and the temperature of the convection heat exchange surfaces in the neighbourhood of the outlet from the vortex chamber.

Due to the swirling of the gases in the vortex chamber, suspended particles experience a centrifugal action, with the result that particles are thrown to the walls of the chamber from which the particles pass downwardly through the duct 26 into the auxiliary furnace chamber to join the slag pool on the floor thereof and pass from the auxiliary furnace chamber into the slag tank. As a consequence, very little solid matter is carried by the gases from the vortex chamber and those particles that pass with the gases into the convection sections are too cool to stick to the convection heat exchange surfaces.

The recirculated gases carry back solid entrained matter to the vortex chamber and as a consequence the effectiveness of the vortex chamber in effecting separation of solid matter from the gases is increased.

Figure 6 illustrates an alternative arrangement for the driving of the fan for effecting gas recirculation. An air compressor 100' takes in air from the atmosphere at 151 and delivers the compressed air to a gas turbine 152 by way of an air heater 92', the air leaving the gas tur-
bine being supplied to the cyclone furnace as combustion air. The air heater 92' is heated by hot furnace gases passing through a duct 154, the gases being extracted from a point in the gas flow path through the steam generator described above beyond the convection vapor generating section 61 and suitably between the convection heat exchange sections 61 and 62. The compressor 100', the turbine 152 and a gas recirculation fan 111' are operatively coupled together by a shaft 156. The fan 111' takes in furnace gases from a suitable location in the gas flow path through the steam generator, which may be after the air heater 92' or after the economizer 62 and discharges these gases through a duct 112' to the interior of the casing 113 which surrounds the vortex chamber 25. The turbine 152 develops sufficient power to drive not only the compressor 100' but also the gas recirculating fan 111'. Since such an arrangement of gas turbine is not self-starting, an electric motor (not shown) of relatively small power is provided for driving the compressor 100' during the starting-up period. The use of a gas turbine to drive the gas recirculating fan in the manner described enables the power required for this purpose to be obtained virtually at boiler efficiency.

The steam generating unit described above is compact and requires little head-room. Moreover, only the cyclone and the auxiliary furnace chamber, the tubes of which are studded and covered with refractory material, are subjected to particularly high temperatures. Due to the amount of gas recirculated, a large mass flow rate of gases over convection heat exchange surfaces is obtained, the gases being at the highest temperature which may be used without the danger of deposition of sticky slag on convection surfaces. This facilitates the attainment of high vapour temperatures and leads to an economy in heat exchange surfaces. The duration of operation between intervals for cleaning the unit is high since there is no deposition of sticky slag on the convection surfaces.

Regulation of the degree of superheat of steam leaving the generator may be attained in known manner by the use of an attemperator associated with the superheater, while if a reheater is also provided, gas-by-pass means may be provided to enable the gas flow over the reheater to be varied in order to control the final temperature of the reheated steam. In another embodiment of the invention the recirculated gas is introduced at an end of the vortex chamber through means such as suitably directed ports or an opening provided with directing vanes, adapted to effect swirling of the recirculated gases in the vortex chamber. Alternatively or in addition the hot furnace gases may be induced at the end of the vortex chamber.

In some instances the vortex chamber may be arranged for the delivery of separated dust to a hopper. Thus, in one embodiment, a part of the vortex chamber beyond the inlet to the inwardly extending throat 31 is unoccupied by hot or recirculated gas inlet ports and is formed in a lower part of its circumferential wall with a dust outlet port or dust outlet ports leading to a subjacent hopper for the collection of separated dust in solid particulate form. Fig. 7 shows diagrammatically the fluid flow and gas flow in a forced flow vapor generating and superheating unit; or liquid circulating pumps 36 pumps liquid in three lines which are arranged substantially in parallel. In one line the liquid flow is through the boiler or convection vapor generating section to the drum. In a second, the flow is through the vapor generating tubes of the vortex chamber to the drum, and in the third line the flow of the pumped liquid is through the vapor generating tubes of the cyclone furnace to the drum. There is also a line from the discharge side of the circulating pump for optionally diverting a part of the pumped liquid through at least a part of the economizer.

In the Fig. 7 unit a recirculating fan is shown as recirculating cooled heating gases from a position about a third of the stack and delivering the recirculated gases to the vortex chamber. From the latter, the gases pass over the convection sections constituting the superheater, the boiler, and economizer, to the drum.

While in accordance with the provisions of the statutes, we have illustrated and described herein the best form and mode of operation of the invention now known to us, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention covered by our claims, and that certain features of our invention may sometimes be used to advantage without a corresponding use of the other features.

What is claimed is:

1. In the generating and superheating of high pressure vapor, the method which comprises the burning of an ash containing fuel at temperatures above the fusion temperature of the ash and simultaneously separating from the combustion gases a predominant proportion of the ash content of the fuel in molten form; absorbing heat of the burning fuel for vapor generation; subsequently transmitting heat from the combustion gases to superheat the generated vapor; withdrawing a percentage of the combustion gases after loss of heat therefrom in the superheating zone; introducing the withdrawn gases substantially tangentially into a gas mixing and particle separating zone through which combustion gases are passing toward the superheating zone; simultaneously introducing the unrecirculated combustion gases into the mixing zone in a tangential manner similar to the manner of introduction of the recirculated gases to augment the whirl producing effect of the latter whereby gas mixing and centrifugal separation of gas suspended particles are effected; and discharging the mixed recirculated and unrecirculated gases from the mixing zone directly into the superheating zone at a temperature below that at which any substantial deposition of particles in sticky condition is liable to occur.

2. The tubular vapor generator comprising, in combination, wall means including vapor generating tubes and forming a cyclone furnace burning an ash bearing fuel and operating at temperatures above the ash fusion temperature, the cyclone furnace having a gas outlet and an outlet for slag in a molten condition with the slag outlet below the level of the gas outlet, other wall means including vapor generating tubes and forming a vortex chamber for centrifugal action, additional wall means forming an enclosure conducting gases from the outlet of the cyclone furnace substantially tangentially into the vortex chamber, a vapor superheater disposed immediately downstream of the vortex chamber and including tubes subject to the heat of the gases issuing from the vortex chamber, a recirculated gas system including a fan and fan inlet ductwork communicating with the gas flow beyond the superheater, said recirculated gas system also including fan outlet ductwork and means associated therewith directing the recirculated gases tangentially into the vortex chamber in a manner similar to the introduction of the unrecirculated gases into the vortex chamber, and further wall means providing an enclosure directing the mixed gases from the vortex chamber to the superheater.

3. In a water tube vapor generating and superheating unit; a furnace normally burning fuel at temperatures in excess of 2000° F. and having a gas outlet; a convection fluid heating section receiving gases from the furnace; wall means forming a vortex chamber having a gas inlet; other wall means forming an intermediate chamber connecting the gas outlet of the furnace with the gas inlet of the vortex chamber and directing the high temperature combustion gases from the furnace tangentially into the
vortex chamber; further wall means forming a gas pass enclosure connecting the gas outlet of the vortex chamber with the convection fluid heating section and causing the combustion gases to pass from the vortex chamber to the convection section, and a recirculated gas system for withdrawing a percentage of the lower temperature combustion gases from a position beyond the convection section; said system including recirculated gas outlets distributed peripherally of the vortex chamber and constructed to direct the recirculated gases substantially tangentially into the vortex chamber in a manner similar to the tangential introduction of the unrecirculated gases and augmenting the latter as to their whirl producing effect; and separate gas flow regulating means for each of said recirculated gas outlets.

4. In a cyclone furnace unit for burning ash-containing solid fuel under slag-forming conditions, a cyclone furnace combustion chamber of substantially circular cross-section arranged with its longitudinal axis substantially horizontal, means for introducing a stream of air and ash-containing solid fuel in suspension into said chamber and effecting a helical path of travel thereof along the circumferential wall of said chamber, said chamber having an outlet passage for products of combustion opening through one end thereof, wall means forming a vortex chamber of substantially circular cross-section arranged with its longitudinal axis substantially horizontal and transversely related to the longitudinal axis of said cyclone furnace chamber and having an inlet, an auxiliary furnace chamber connecting the cyclone furnace outlet and the vortex chamber inlet, said auxiliary furnace chamber having a substantially horizontal slag tap floor and wall means presenting a passage tangential to the vortex chamber for developing a whirling gas flow therein, and a gas outlet formed at one end of said vortex chamber, and convection heated fluid heating tubes arranged to be heated by the gases leaving said vortex chamber gas outlet.

5. In a cyclone furnace unit for burning ash-containing solid fuel under slag-forming conditions, a cyclone furnace combustion chamber of substantially circular cross-section arranged with its longitudinal axis substantially horizontal, means for introducing a stream of air and ash-containing solid fuel in suspension into said chamber and effecting a helical path of travel thereof along the circumferential wall of said chamber, said chamber having an outlet passage for products of combustion opening through one end thereof, wall means forming a vortex chamber of substantially circular cross-section arranged with its longitudinal axis substantially horizontal and transversely related to the longitudinal axis of said cyclone furnace chamber and having an inlet communicating with said outlet passage and arranged tangentially of the vortex chamber for developing a whirling gas flow therein, a gas outlet formed at one end of said vortex chamber, a high temperature vapor superheater including a bank of spaced tubes disposed transversely of gas flow immediately subsequent to the gas outlet of the vortex chamber, and a gas recirculation system withdrawing a percentage of the gases after loss of heat therefrom in the superheating and introducing the withdrawn gases substantially tangentially into the vortex chamber.

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