

March 25, 1969

W. W. SCHROEDTER
MULTICIRCUIT RECIRCULATION SYSTEM FOR VAPOR
GENERATING POWER PLANT

3,434,460

Filed Nov. 30, 1966

Sheet / of 2

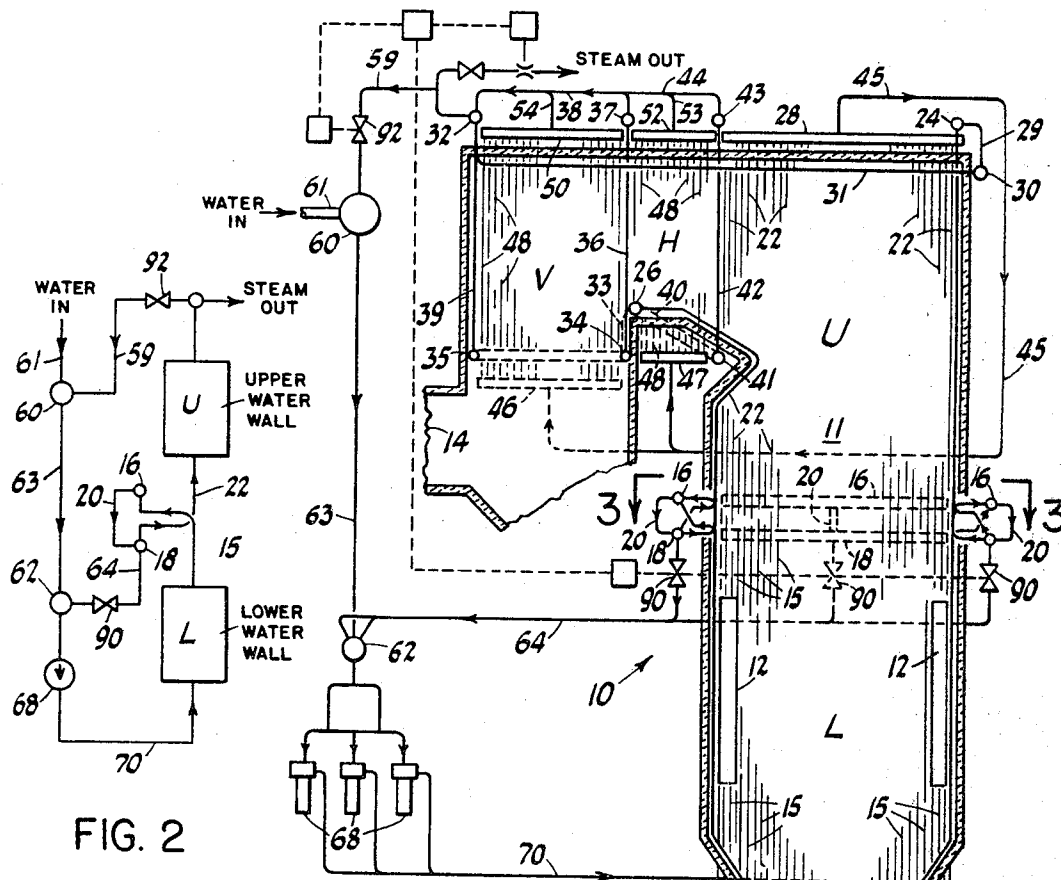


FIG. 2

FIG. 1

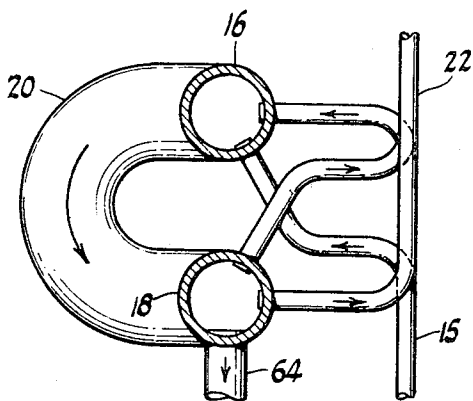


FIG. 4

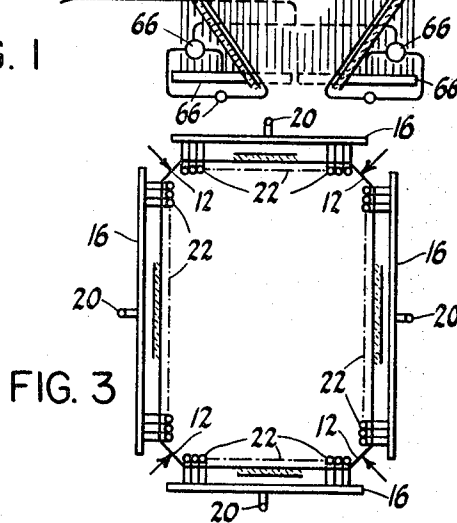


FIG. 3

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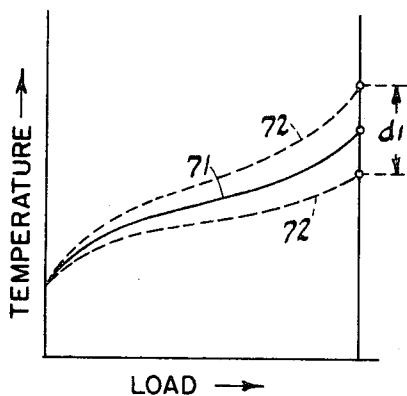


FIG. 5

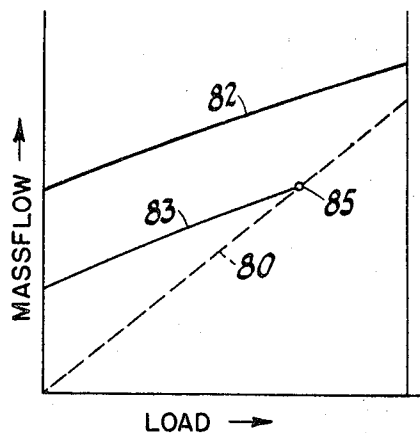


FIG. 8

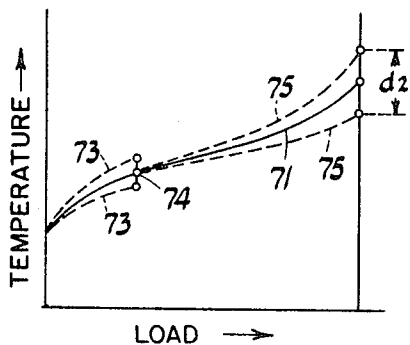


FIG. 6

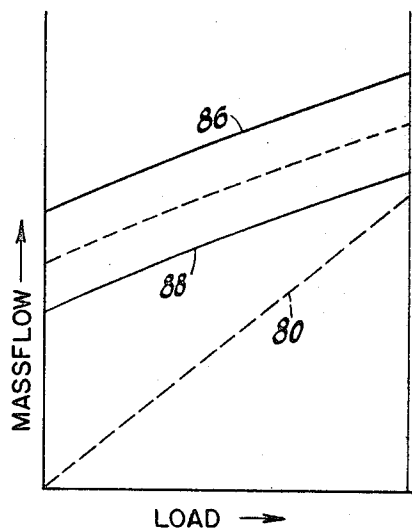


FIG. 9

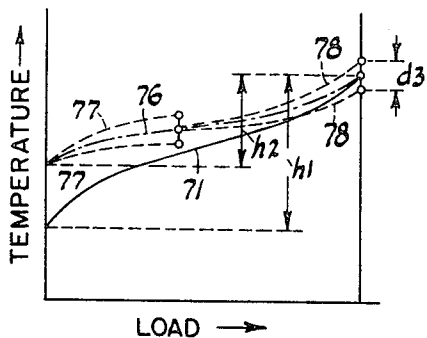


FIG. 7

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MULTICIRCUIT RECIRCULATION SYSTEM FOR VAPOR GENERATING POWER PLANT

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8 Claims

ABSTRACT OF THE DISCLOSURE

The invention relates to a forced through flow vapor generator of the type commonly called combined circulation vapor generator in which a recirculation circuit is superimposed upon the through flow circuit in parallel flow relation therewith. The invention discloses the use of two or more recirculating circuits interconnected for parallel flow and encompassing two or more furnace heating surface portions. These circuits are provided with recirculating pump means and automatic or manual controls which enable the designer and operator to reduce or eliminate recirculation in selected circuits at selected operating loads of the vapor generator. Substantial improvement of the economy can thereby be achieved with respect to recirculating pump size as well as pumping power, and greater uniformity of the temperature of the working fluid passing through the tubular heating surface of the furnace walls.

In large modern high pressure vapor generators, one common design makes use of a furnace center tubular wall. Another employs a single open furnace chamber for reasons of economy and simplicity. One important function of the center tubular wall when connected to the outer walls' tubular surface for serial flow, is to encourage uniformity of the temperature of the working fluid as it leaves the various parallel tube circuits of the outer furnace walls, since mixing of the fluid takes place when it passes from the center wall to the outer walls by way of inlet and outlet headers.

In an open furnace, i.e. a furnace without a center wall, non-uniformity of the temperature or heat pickup can be reduced by recirculating a selected portion of the fluid around the furnace walls, not only at low vapor generating loads but throughout the entire load range. This type of recirculation is quite suitable for vapor generators of medium capacity range. However, vapor-electric generating plants are presently designed and built for electric generator capacities of well over 500 mw. The recirculating pumps needed for vapor generators of such large capacity are uneconomical in operation because of their uncommonly large size.

Another furnace wall design which tends to diminish nonuniformity of the temperature or heat content of the fluid at the furnace wall outlet makes use of intermediate mixing headers. These headers divide the parallel furnace wall circuits into serially connected groups. To protect the furnace tubes at low loads in furnaces built without fluid recirculation, the provision of mixing headers is sometimes combined with the use of a so-called double pass and the use in the furnace wall of smaller diameter tubes for the purpose of increasing the mass flow velocity within the tubes. While mixing headers are desirable, employment of double passes and smaller diameter tubes introduces design and construction problems which may render their use uneconomical and undesirable.

The present invention discloses a multi-circuit recirculation system in combination with mixing headers. This system eliminates the use of double passes or the use of smaller diameter furnace wall tubes for the purpose of

increasing mass flow. Thus, in accordance with the present invention, two or more recirculating circuits are arranged for parallel flow, with a common recirculation pump. They may be provided with means for controlling the flow through the multiple recirculating circuits. This control can be accomplished by designing each circuit for a specific pressure drop to obtain a predetermined flow in each circuit and/or by providing a pump which either operates at variable speed or at substantially constant speed, having the inherent characteristic of the pumped flow varying inversely with the pumped head. A detailed description of a recirculating pump and its operation in connection with a recirculation circuit is given in U.S. Patent No. 3,135,252 issued to W. W. Schroedter on June 2, 1964. Or valves may be provided for controlling the flow through the various circuits independent of the vapor output or in response thereto. This multi-circuit recirculating system is especially suitable for large vapor generating power plants of capacities in excess of 500 mw., since the above combination permits the use of recirculating pumps of smaller capacity than would be required for tube protection if only one recirculating circuit were provided. The reduction in pump size is possible because at higher vapor generating loads the upper furnace recirculating circuit is made partially or fully inactive without reducing the protection afforded to the tubes in the lower furnace. Recirculating pump power is therefore primarily required for the lower circuit only. At the same time, the distribution between the multi-circuit, in addition to being a function of load can further be controlled by manipulation of valves or pump speed.

It is accordingly a primary object of the invention to reduce the recirculating pump power employed in a forced through flow vapor generator of the combined circulation type when operating in the higher vapor generating load range.

It is another object of the invention to promote uniformity of heat content or temperature of the working fluid leaving the furnace wall circuits by providing mixing headers in combination with the recirculating circuits of a combined circulating forced through flow vapor generator.

It is a further object of the invention to establish and maintain sufficient mass flow of the working fluid through the furnace tubes for adequately cooling these tubes at low loads or during start-up and shutdown operation, without resorting to double pass tube construction or reduced tube diameter.

It is an additional object of the invention to provide a control system in connection with the herein disclosed multi-circuit recirculating system, which enables the designer and operator to increase recirculation through those portions of the furnace tube wall that are subject to high heat absorption rates.

Accordingly, when applying the invention to a forced through flow vapor generator operating under variable load demand, the above is accomplished by providing a furnace having a lower fluid heating tube section in a high heat release zone, an upper fluid heating tube section in a relatively low heat release zone, a through-flow line for flowing a once-through flow quantity of the working fluid in series flow relation through the lower and upper fluid heating tube sections, a tube circuit which may be valve controlled for recirculating a second quantity of the working fluid through the lower fluid heating tube section and back to the inlet thereof, a tube circuit which may be valve controlled for recirculating a third quantity of the working fluid in series flow relation through the lower and upper fluid heating tube sections and back to the inlet of the lower fluid heating tube section, a recirculating pump included in the above recirculating circuits floating on the through flow line for establishing a posi-

tive recirculation flow through the fluid heating tube sections and through the recirculating circuits in addition to the once-through flow.

Other objects and advantages of the invention will become apparent from the following description of an illustrative embodiment thereof when taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a schematic side elevation of the tube and pipe layout of a forced through flow steam generator incorporating a recirculating system having two circuits arranged for parallel flow, in accordance with the invention;

FIGURE 2 is a greatly simplified line diagram of the circuit layout shown in FIGURE 1;

FIGURE 3 is a plan section of line 3—3 of FIGURE 1;

FIGURE 4 is an enlarged view of the mixing headers dividing the furnace into upper and lower recirculating circuits;

FIGURE 5 is a diagram showing deviation of the temperature of the working fluid when passing the fluid through the wall tubes of a furnace not equipped with intermediate mixing vessels;

FIGURE 6 is a diagram showing the improved uniformity of the temperature of the working fluid when passing the fluid in series through the tubes of a furnace having a furnace center wall;

FIGURE 7 is a diagram showing the reduced degree of deviation of the temperature of the working fluid while passing through the tubes of the furnace walls when the furnace is equipped with a recirculating circuit;

FIGURE 8 is a diagram showing mass flow of the working fluid entering the lower and upper recirculating circuits of a vapor generator designed in accordance with the invention and with the unit so organized that recirculation through the upper circuits ceases at a predetermined vapor generating load; and

FIGURE 9 is a diagram similar to FIGURE 8, however, showing recirculation through a unit designed to maintain flow through both recirculating circuits up to and above the nominal maximum vapor generating load.

Description of the steam generator

Referring now to the drawings wherein like reference characters are used throughout to designate like elements, the illustrative and preferred embodiment of the invention depicted in FIGURE 1 includes a vapor generator designated generally as 10 and comprising a furnace chamber 11 having an upper portion U and a lower portion L, a horizontal gas pass H extending from the upper furnace portion, and a vertical gas pass V extending downwardly from the horizontal pass H. Air and fuel for burning are introduced into the furnace by way of burners 12 which in the embodiment shown are mounted in the corners of the furnace chamber as indicated in FIGURE 3. The rising combustion gases leave the furnace 11 by way of the horizontal gas pass H, vertical gas pass V, and gas outlet duct 14. The front, side, and rear walls of the furnace portion L are lined with closely spaced tubes 15. After passing through the furnace walls at the upper end of chamber portion L, these tubes terminate in headers 16 positioned in front of and parallel to the respective furnace walls. A similar set of headers 18 is provided directly below headers 16 and are connected thereto by conduits 20. The walls of the upper furnace portion U are also lined with closely spaced tubes 22 which originate in headers 18. The function of headers 16 and 18 is to mix the fluid as it passes from the lower furnace portion L to the upper furnace portion U. These headers and the associated tubes 15 and 22 are shown in greater detail in FIGURE 4. Tubes 22 lining the front wall of the upper furnace portion U terminate in header 24. Those lining the rear wall terminate in header 26 and those lining the side walls in headers 28.

From the front wall header 24 the fluid passes through conduit 29, header 30, and roof tubes 31 to a common

collecting header 32. From rear wall header 26 a portion of the fluid passes through conduit 33, header 34, and hanger tubes 36 which are widely spaced across the furnace width to form a screen, into header 37, and thence by way of conduit 38 to collecting header 32. Some of the fluid also passes from header 34 to header 35, then through tubes 39, which line the rear wall of the vertical gas pass V, to collecting header 32. And a third quantity flows from header 26 through conduit 40 into header 41 and thence through screen tubes 42, header 43, and tubes 44 into collecting header 32. From the side wall header 28 the fluid flows through conduits 46 into headers 46 and 47 from which tubes 48 originate. These tubes line the side walls of the gas pass H and gas pass V and terminate in headers 50 and 52 from which the fluid flows to collecting header 32 by way of conduits 53 and 54.

The through flow fluid collected in common header 32 from the furnace walls as herein above described then flows to a superheater (not shown), before being delivered to a point of use.

In a combined circulation boiler the through flow fluid quantity flowing through the furnace tubes is reinforced by a recirculating fluid quantity, in order to maintain a sufficiently high velocity or mass flow to prevent heat damage to the tubes. For this purpose some of the fluid collected in collecting header 32 from the furnace walls is conducted to a primary mixing vessel 60 by way of conduit 59. Into mixing vessel 60 is also discharged by way of conduit 61 the through flow portion of the fluid quantity before it passes through the furnace tubes. This through flow quantity which may have earlier been preheated in an economizer (not shown) is mixed in vessel 60 with the recirculating quantity returned from header 32, and flows from this vessel 60 to a secondary mixing vessel 62 by way of conduit 63. A second recirculating quantity which has passed only through the tubes of lower furnace portion L in contrast to the earlier named recirculating quantity which has passed through the tubes of both the lower furnace portion L and the upper furnace portion U, is received from header 18 by way of conduit 64. This second recirculating fluid quantity then is mixed with the fluid received from primary mixing vessel 60, with the mixture flowing to the furnace wall distributing headers 66 by way of recirculating pumps 68 and conduits 70.

To facilitate ready understanding of the invention, the flow circuits of the vapor generator 10 are shown in FIGURE 2 in a greatly simplified line diagram.

How uniformity of fluid temperature leaving the furnace walls is improved

Referring now to FIGURE 5, the solid line 71 shows the average temperature rise of the fluid as it is heated while passing through the continuous tubes of the walls of a typical furnace without recirculation of the working fluid. The amount of heat absorbed by the parallelly arranged tubes of a furnace wall varies across the width of the furnace wall and is generally low in the corners of the furnace chamber. This is due to the geometry of the furnace and of the flow path of the combustion gases. Also unequal slag accumulations on the walls of the furnace contribute to nonuniformity of heat absorption. Accordingly, the temperature of the fluid when measured across the furnace wall has become nonuniform at the furnace wall outlet after the fluid has passed through the furnace wall tubes. The maximum and minimum values deviating from the average value 71 are indicated by the upper and lower dash-dash lines 72 in FIGURE 5. Such nonuniformity of the fluid temperature if unchecked creates undesirably high thermal stresses in some of the furnace tubes. This, when coupled with the high temperature to which these tubes are exposed, may cause failure of the tubes and force shutdown of the plant for repair, unless costly alloy tubing is used possessing superior strength when exposed to elevated temperatures.

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As earlier pointed out herein above the inequality of the fluid temperature can be somewhat reduced by dividing the furnace wall heating surface into sections or divisions which are separated by fluid mixing headers. For instance, furnace center walls have been used in series flow with the outer wall and separated therefrom by a header wherein mixing of the fluid can take place. The effect upon the reduction of nonuniformity of the fluid temperatures when dividing the furnace heating surface is illustrated in FIGURE 6, where the solid line 71 again shows the average temperature rise of the fluid. The upper and lower dash-dash lines 73 indicate the maximum and minimum deviation of the fluid temperature from the average temperature while the fluid passes through the center wall tubes or other first division of the furnace heating surface. This deviation is wiped out by mixing of the fluid at 74 when passing from the outlet of the center wall or first division through a mixing header to the inlet of the outer walls or other divisions of the furnace heating surface. Upper and lower dash-dash lines 75 indicate the minimum and maximum deviation of the fluid temperature from the average temperature when continuing fluid flow through the remaining divisions of the furnace walls. Thus the final temperature deviation is much less in a furnace equipped with header separated divisions than in a furnace without such divisions of the furnace heating surface.

The nonuniformity of the furnace wall fluid temperature can further be greatly reduced by the multicircuit recirculation system which is the subject of the herein disclosed invention. This system, in combining mixing headers such as 16 and 18 with recirculation of the fluid around the furnace tubes, makes possible a substantial increase in the degree of uniformity of the fluid temperature at the furnace outlet. Thus with reference to FIGURE 7, the solid line 71 again indicates the average temperature rise in the furnace wall tubes in a furnace not equipped with fluid recirculation nor mixing headers. The dot-and-dash line 76 indicates the average fluid temperature when recirculation is resorted to. Dash-dash lines 77 show the maximum and minimum deviation of the temperature from the average temperature rise indicated by dot-and-dash line 76 when the fluid passes through tubes 15 in the lower furnace portion L, and dash-dash lines 78 show the maximum and minimum deviation of the temperature when the fluid passes through tubes 22 in the upper furnace portion U.

The use of the recirculating circuit in itself reduces the heat content difference between the fluid entering and the fluid leaving the furnace wall tubes, as is indicated by h_1 and h_2 in FIGURE 7. However, the employment of a dual circuit recirculating system additionally improves uniformity of the fluid temperature across the furnace width as indicated by the comparison between d_1 (FIG. 5), d_2 (FIG. 6), and d_3 (FIG. 7).

Reduction of recirculating pump power

Referring now to FIGURE 8, numeral 80 designates a curve representing the mass flow (pounds per hour) of the through-flow quantity when plotted against percentage of generator load. Curve 82 represents the mass flow of the recirculated quantity passing through the lower furnace tubes 15; and curve 83, the mass flow of the recirculated quantity passing through the upper furnace tubes 22.

The recirculating pump cooperating with these recirculating circuits may be of the constant speed or variable speed type and of such limited capacity that the recirculation through the furnace tubes 22 in the upper furnace portion U ceases at a predetermined load point 85, and only recirculation through the furnace tubes 15 continues up to a desired higher load which may be maximum load. Using two or more recirculating circuits in accordance with the present invention, therefore, as earlier stated, makes it possible to reduce recirculating pump power

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substantially without sacrificing safe velocity of the fluid in the high heat absorption zone of the lower furnace tubes during high load operation, and in addition reap the benefit of more uniform temperatures at the furnace tube outlets.

In FIGURE 9, curves 86 and 88, respectively, again represent the mass flow through the lower furnace tubes 15, and the upper furnace tubes 22 as plotted against generator load. In this design recirculation through both circuits, although diminishing with increase in load, remains active up to maximum load by providing a recirculating pump of higher capacity. This pump capacity, however, is still considerably lower than the pump capacity which would be required if a single recirculating circuit were employed. In a multicircuit recirculating system the recirculating quantity passing through the upper furnace tubes 22 is greatly reduced during the higher load range in circuits in which the working fluid has a high specific volume causing a correspondingly high pressure drop.

Control of the flow through the various recirculating circuits

Several methods can be used in regulating the flow of the working fluid through the two or more recirculating circuits hereinabove described. Some automatic control can be established by providing a constant speed recirculating pump having the inherent characteristic of pumped flow varying inversely with pumped head. This, coupled with a predetermined built-in flow resistance of the recirculating circuit, such as by pipe diameter, orifices, or throttle valves, enables the designer to match the recirculated flow with the cooling requirements in the different furnace wall portions. Or a variable speed recirculating pump may be provided which enables the operator at any desired load to regulate or halt recirculation through the tubes of the upper furnace portion U as required by changing pump speed.

To proportion the recirculated flow through the various furnace portions after the unit is put into operation, control valves may be installed in each circuit. Thus in the lower circuit including furnace tubes 15, valves 90 are provided. In the upper circuit including furnace tubes 15 and 22, valves 92 are provided. These valves serve the purpose of dividing the flow through the two recirculating circuits as may be required by the heat absorption, between the upper and lower furnace portion at various loads.

If desired, valves 90 and 92 may also be automatically operated in response to boiler load for the purpose of diminishing, increasing, or arresting recirculating circuits at a given load.

While I have illustrated and described a preferred embodiment of my invention, it is to be understood that such is merely illustrative and not restrictive and that variations and modifications may be made therein without departing from the spirit and scope of the invention. I therefore do not wish to be limited to the precise details set forth but desire to avail myself of such changes as fall within the purview of my invention.

I claim:

1. In a forced through flow vapor generator operating under a variable load demand, and having a furnace chamber for producing hot gases, said furnace chamber having a first radiant heat absorbing tubular furnace wall section in a relatively high radiant heat release zone, a second radiant heat absorbing tubular furnace wall section in a relatively low radiant heat release zone, a through-flow line for flowing a once-through flow quantity of the working fluid in series flow relation through said first and said second tubular furnace wall sections, means for recirculating a second quantity of the working fluid in series flow relation through said first and said second tubular furnace wall sections and back to the inlet of said first tubular furnace wall section; the improvement which comprises first fluid mixing header means for

receiving the working fluid from said first wall section, second fluid mixing header means for discharging the working fluid to said second wall section, conduit means for connecting said first and second fluid mixing header means, and means for recirculating a third quantity of the working fluid through said first tubular furnace wall section via said first mixing header, and back to the inlet thereof.

2. A forced once-through flow vapor generator as defined in claim 1, having flow restricting means for establishing a desired ratio of the flow returning from said first section to the flow returning from said second section.

3. A forced once-through flow vapor generator as defined in claim 1, wherein said second and third quantities recirculating means include recirculating pump means operating at substantially constant speed and having the inherent characteristic of pumped flow varying inversely with pumped head floating on the working fluid flow for establishing a positive recirculation flow through said fluid heating wall sections and said recirculating means in addition to the once-through flow.

4. A forced once-through flow vapor generator as defined in claim 1, wherein said second and third quantities recirculating means include recirculating pump means operating at variable speed.

5. A forced once-through flow vapor generator as defined in claim 2, wherein said flow restricting means include valve means for regulating the proportion of the quantities recirculating through said first and said second fluid heating tube sections.

6. In a forced through flow supercritical vapor generator having a variable vapor demand rate and a working fluid through flow line, a furnace chamber lined with separate radiant heat absorbing furnace wall tubular sections connected in series for series through flow and requiring a minimum safe velocity of working fluid there-through, a relatively high radiant heat release zone and a relatively low radiant heat release zone in said furnace, a first section located in said high heat release zone and having a low through flow velocity, a second section located in said low heat release zone and having a high through flow velocity, means connected with the inlet of said first section for supplying through flow fluid at supercritical pressure to said inlet, a recirculating pump connected across both sections and recirculating working fluid through both sections and having a suction side and a discharge side connected with said through flow line and combining said recirculating fluid with said through flow

fluid; the improvement which comprises first fluid mixing header means for receiving the working fluid from said first section, second fluid mixing header means for discharging the working fluid to said second section, conduit means for connecting said first and second mixing header means, and conduit means for connecting the outlet end of said first section and the inlet end of said second section with the suction side of said pump, and regulating means for increasing or decreasing the ratio of flow returning from said first section to the flow returning from said second section.

7. A vapor generator as claimed in claim 6 in which said regulating means include said recirculating pump operating at substantially constant speed and having the inherent characteristic of pumped flow varying inversely with pumped head floating on the working fluid flow for establishing a positive recirculation flow through said sections in addition to said through flow.

8. In a forced through flow vapor generator as defined in claim 6, the method of operating the generator in the high vapor generating load range to reduce the recirculating pump power, including the steps of:

- (1) passing a through flow quantity of the working fluid through said high radiant heat release furnace wall section and through said low radiant heat release furnace wall section in series flow;
- (2) recirculating a first quantity of said working fluid through both said sections in series flow, in addition to said through flow quantity; the improvement which comprises the additional steps of:
- (3) recirculating an additional second quantity of working fluid through said high radiant heat release furnace wall section; and
- (4) increasing or decreasing the ratio of said second quantity to said first quantity as the vapor generating load increases or decreases, respectively.

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