Nov. 12, 1957 W. H. ARMACOST ET AL 2,812,747

METHOD AND APPARATUS FOR STEAM TEMPERATURE CONTROL

Filed July 28, 1954 2 Sheets-Sheet 1

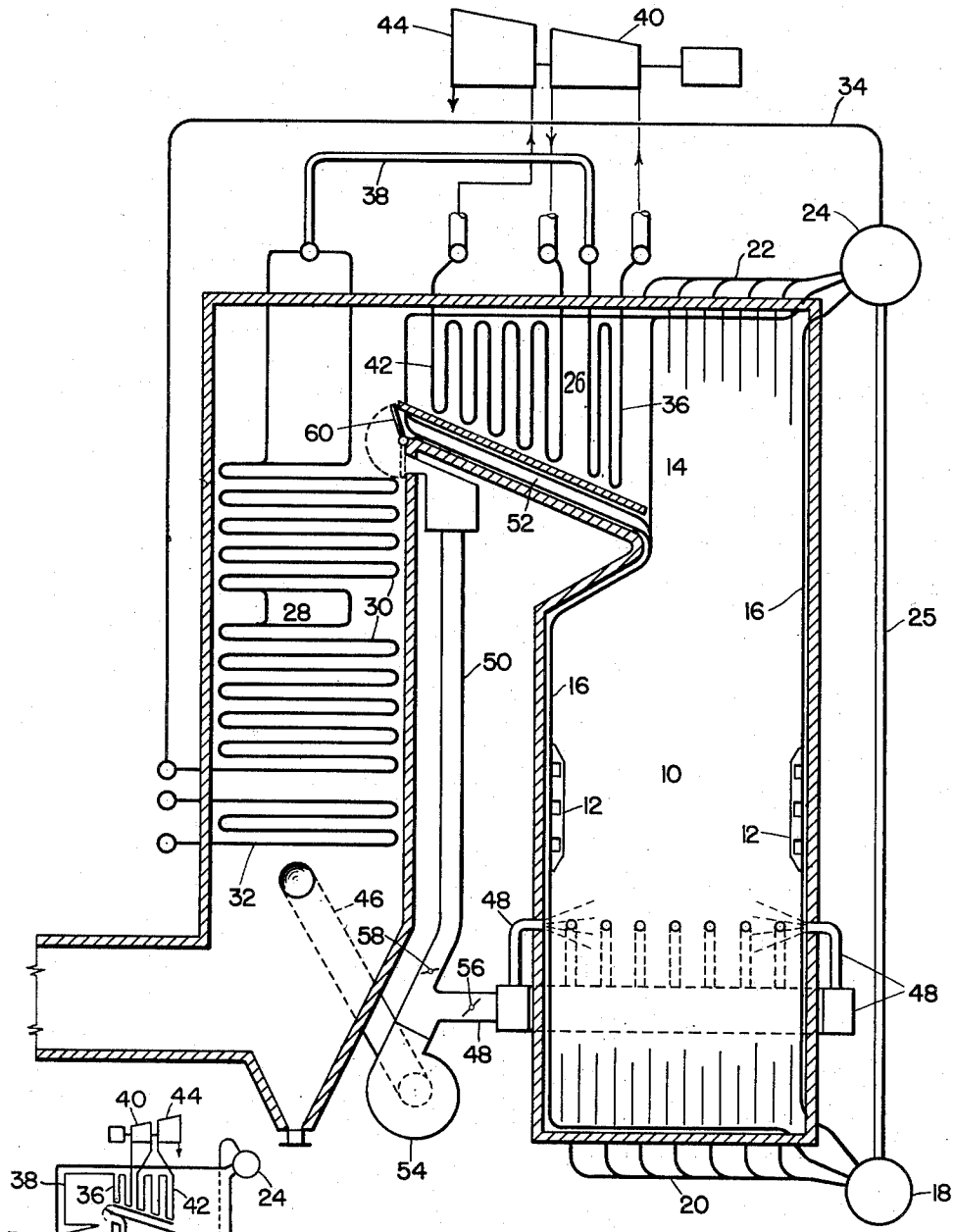


FIG. 1

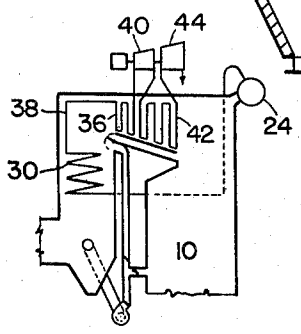


FIG. 1A

INVENTORS:
WILBUR H. ARMACOST
ARTHUR C. FIRL

BY Arthur C. Firl

ATTORNEY

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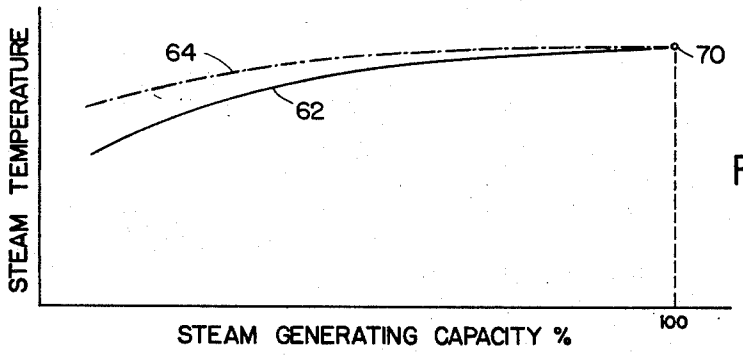


FIG. 2

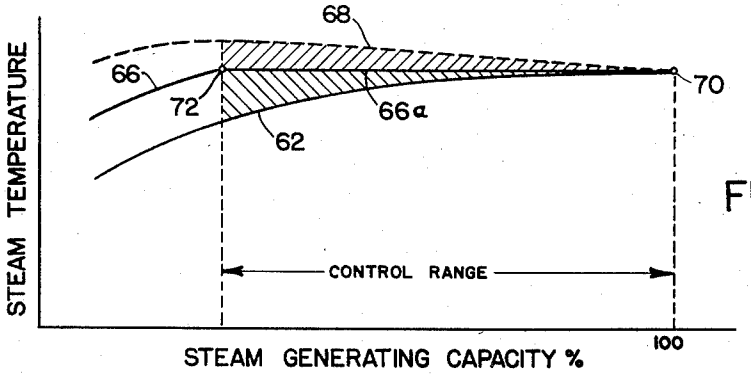


FIG. 3

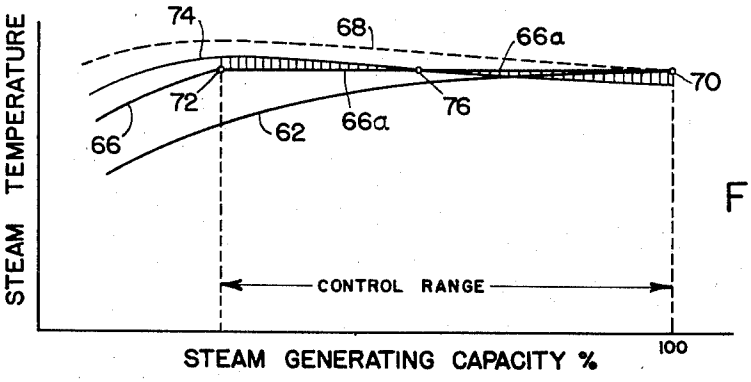


FIG. 4

WILBUR H. ARMACOST
ARTHUR C. FIRL
INVENTORS

BY Arthur C. Firl

ATTORNEY

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METHOD AND APPARATUS FOR STEAM TEMPERATURE CONTROL

Wilbur H. Armacost, Scarsdale, N. Y., and Arthur C. Firl, Ridgefield Park, N. J., assignors to Combustion Engineering, Inc., New York, N. Y., a corporation of Delaware

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8 Claims. (Cl. 122—478)

This invention relates to vapor power plants in which superheated vapor is generated. More specifically this invention deals with steam generators operating under the reheat cycle in which the superheated steam after having given up part of its energy in a turbine is reheated and returned to the turbine for further use.

In the operation of modern high temperature high pressure steam power plants it is essential that the temperature of the steam entering the steam turbine be held at a constant value over a wide range of steam generating loads. Moreover in steam power plants operating under the reheat cycle it becomes necessary to control not only the temperature of the superheated steam or primary steam but also the temperature of the reheated or secondary steam and to maintain both of these temperatures at a constant predetermined value over a wide range of load.

One way to accomplish this is to control the reheated steam temperature by conventional means such as tilting burners, gas by-passing or gas recirculation and to lower the temperature of the superheated steam by desuperheating.

When controlling the steam temperature in this manner it is essential that the superheater be provided with sufficient heating surface to raise the temperature of the steam prior to desuperheating to a value which is equal or in excess of the desired steam temperature at all loads.

Such control by desuperheating accordingly requires steam heaters which are oversized and costly and lowers overall operating efficiency.

It is accordingly the main object of our invention to provide a superior and more convenient method of regulating the temperature of the primary or superheated steam and that of the secondary or reheated steam independently of each other and without desuperheating.

It is another object of our invention to appreciably extend the capacity range over which the primary and secondary steam temperatures can be controlled within economic limits.

A further object of our invention is to reduce the first cost of the steam heaters for a comparable size of boiler unit.

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:

Fig. 1 is a diagrammatic representation of a steam generating power plant operating under the reheat cycle and equipment with our inventive improvement.

Fig. 1A is a diagrammatic representation of a steam generating power plant similar to Fig. 1 however with steam heaters arranged in a different sequence.

Fig. 2 is a diagram showing a set of steam temperature curves plotted against steam generator capacity in a unit operating without gas recirculation or other steam temperature control.

Fig. 3 is another diagram showing a set of curves indicating the steam temperatures for various steam generator capacities and when gas is recirculated into the furnace chamber to control the reheated steam temperature, and desuperheating is resorted to for superheat temperature regulation.

Fig. 4 shows another set of steam temperature curves plotted against steam generator capacity when controlling the temperature by means of gas recirculation and the superheat temperature by means of both gas by-passing and gas recirculation.

Referring now to Fig. 1 the reference character 10 denotes a furnace generally of rectangular cross section into which fuel and air is fed by way of burners 12 and from which combustion gases are discharged through an outlet 14 at the upper end thereof. Tubes 16 line the walls of furnace chamber 10 and receive water from a drum 18 through feed tubes 20. Steam and water is discharged by tubes 16 through steam delivery tubes 22 into a steam and water drum 24. There the water is separated from the steam and returns through pipes 25 to drum 18.

The combustion gases after leaving furnace outlet 14 pass through a horizontal gas offtake 26 into a vertical gas pass 28 from which they are discharged into the atmosphere through a stack (not shown). Gas pass 28 contains a first stage superheater 30 and may house other heat absorbing apparatus such as economizer 32. The steam after having been separated from the water leaves drum 24 by way of steam tubes 34 and is delivered to the first stage superheater 30. After having been partially heated in first stage superheater 30 the steam then flows to the final superheater heating section 36 by way of pipe 38, from where it is then delivered to the high pressure turbine stage 40.

Having given off some of its energy the steam is returned to a reheater 42 for additional heating and is then delivered to the low pressure turbine stage 44 for further extraction of energy.

To facilitate control of the reheat steam temperature burners 12 may be of the tilting type which makes it possible to raise or lower the body of flame within the furnace chamber thereby altering the temperature of the gases passing over the heating surface of superheater 36 and reheater 42. Disregarding the effect on superheater 36 the temperature of the reheated steam can in this manner be maintained at a constant value over a given load range.

The reheated steam temperature can also be controlled by conducting relatively cool combustion gases back into the furnace chamber 10. The temperature of the gases in the combustion chamber is thereby lowered. This reduces the amount of heat absorbed by the furnace tubes 16 and makes more heat available at the furnace outlet, thereby raising the temperature of the reheated steam.

In thus controlling the reheated steam temperature by regulating the temperature of the combustion gases leaving the furnace chamber 10 as outlined above the amount of heat absorbed by the finishing off superheater stage 36 and that of the first stage superheater 30 is of course also changed perforce. It accordingly becomes necessary to readjust the temperature of the superheated steam to meet the design temperature thereof which adjustment may not be of the same magnitude as that required for the reheated steam. Heretofore under conditions as above outlined, regulation of the superheated steam temperature has been accomplished by providing an excess of superheater heating surface and desuperheating the temperature of the steam down to the desired value. This obviously is uneconomical both in operation as well as in initial installation costs.

Our herein disclosed improvement on the other hand increases overall plant efficiency by largely eliminating

the necessity for desuperheating. Furthermore it permits the use of a superheater having less heating surface for comparable capacity and therefore being less costly than a conventional superheater designed for desuperheating at the lower range of loads.

To accomplish the above, gas recirculating ducts 46, 48 are provided leading from the lower portion of vertical gas pass 28 to the furnace chamber 10. In addition gas recirculating ducts 46, 50 are provided between the lower portion of vertical gas pass 28 and the upper portion thereof to a point directly ahead of the primary superheater 30. A fan 54 cooperating with the said ducts 46, 48 and 50 draws gas out of the lower portion of gas pass 28 and delivers this recirculated gas under pressure through ducts 48 into the furnace chamber. The amount of gas thus recirculated into the furnace is largely controlled by means of damper 56. Fan 54 (or, if preferred, a second fan not shown) can also deliver recirculated combustion gases through duct 50 into the upper portion of vertical gas pass 28. Damper 58 in cooperation with damper 56 controls the flow of gas thus recirculated through duct 50.

There is also provided in the embodiment of Fig. 1 illustrating our invention, a gas by-pass 52 permitting gas to flow from the upper part of furnace chamber 10 to a point behind reheater 42 and directly ahead of primary superheater section 30. To facilitate control of this flow there is disposed at the outlet of by-pass 52 a damper 60 which is so arranged that it can restrict either the flow through by-pass 52 or the flow out of recirculating duct 50.

In the operation of a reheat steam generator as herein described, the reheat temperature may be regulated by means of tilting burners 12, by means of gas recirculated into combustion chamber 10, or by both tilting of burners and gas recirculation. In each case the raising or the lowering of the gas temperature at the furnace outlet 14 will affect not only the heat absorption of the reheater 42 but also that of the final stage superheater 36 and the first stage superheater 30.

If the load is decreased to meet low load operating requirements, the temperature of the reheated steam falls off at a greater rate than that of the superheated steam, because the temperature of the steam to the superheater remains constant whereas the temperature of the steam to the reheater becomes less with a drop in load.

This is graphically illustrated in Fig. 2 which shows two curves 62 and 64. Curve 62 represents the reheated steam temperature characteristic and curve 64 the superheated steam temperature characteristic for varying steam generator load. It should be noted that for sake of simplicity, in the representative unit characterized by the curves of Figs. 2, 3 and 4, the heating surface of the superheater and reheater are proportioned to produce at top load the same steam temperature for the superheat and the reheat. Accordingly starting off at point 70 representing top load the superheated steam temperature 64 does not fall off as rapidly as the reheated steam temperature 62 with reduction in load.

It is the above difference in temperature characteristic between the superheated steam and the reheated steam which makes it necessary to desuperheat steam at lower loads when the reheat steam temperature is held constant by employing temperature control means such as tilting burners, gas recirculation or other means.

The above is illustrated in Fig. 3 wherein are shown three temperature curves 62, 66, and 68. Curve 62 shows the uncontrolled reheat temperature characteristic for various steam generator loads. In order to correct this falling characteristic gas is recirculated into the furnace chamber at loads lower than maximum. By means of recirculation of gas the reheat temperature can be raised from curve 62 to curve 66 which shows a straight line portion 66*a* indicating a constant reheat temperature between 100% capacity and control point capacity. These two extreme capacities represent the upper and lower limit of the control range and are indicated by points 70 and 72 in Figs. 3 and 4. It has been found in actual practice that generally when the reheat temperature is thus controlled the superheat temperature will rise from curve 64 indicated in Fig. 2 to curve 68 shown in Fig. 3. The shaded area between curves 66 and 68 illustrates the amount of desuperheating that becomes necessary at loads lower than maximum. It is this desuperheating of the superheated steam which reduces the overall plant efficiency as the load of the steam generator drops off below maximum.

Our invention eliminates the above lowering of plant efficiency caused by desuperheating, through the introduction of additional gas recirculation through ducts 46 and 50 to a point in the gas flow between the reheater 42 and the first stage superheater 32 and by additionally providing a gas by-pass 52 permitting gas to by pass the finishing off stage of the superheater 36 and the reheater 42.

Fig. 4 illustrates in graphic form how it is possible in our improved organization to install a superheater having less heating surface, and accordingly being less costly, than a comparable superheater utilizing desuperheating as indicated in Fig. 3. Thus in Fig. 4 there are shown four curves representing steam temperatures for various steam generator capacities; three of these curves, namely curve 62, 66 and 68 are the same as those shown in Fig. 3 and represent the uncontrolled reheat steam temperature, controlled reheat steam temperature and uncontrolled superheated steam temperature respectively. A fourth curve 74 represents the as yet uncontrolled superheat steam temperature in an organization provided with our herein disclosed inventive improvement. It will be noted that this curve 74 runs approximately parallel to curve 68, however at a lower temperature range, and bisects curve 66 at point 76. This means that the superheater having a temperature characterized by curve 74 contains less heating surface than the superheater having a temperature characteristic represented by curve 68 (see Fig. 3). If it is assumed that the desired temperature of the superheated steam is the same as the desired temperature of the reheated steam, or in other words, that curve 66, 66*a* not only represents the desired reheat steam temperature held constant within a range between maximum load and control point load (between points 70 and 72), but also represents the desired temperature of the superheated steam held constant within the same load range, then the cross hatched area above curve 66 and below curve 74 and the cross hatched area below curve 66 and above curve 74 represents the amount of controlling that is necessary to raise or lower respectively the superheated steam temperature to the desired steam temperature at the various steam generator capacities.

In operation such control is accomplished by by-passing hot gases through by-pass 52 at loads lying between the maximum or 100% capacity and the capacity represented by point 76. At loads below that represented by point 76 and above the control point load represented by point 72 cooled combustion gases are recirculated through ducts 46 and 50 (see Fig. 1) to a point directly ahead of the first stage superheater section 30 whereby to lower the temperature of the superheated steam accordingly.

In this manner our invention permits the control of both the reheated steam and the superheated steam without resorting to desuperheating. In addition it makes possible the utilization of a superheater having less heating surface, and accordingly having lower initial cost. This reduction in cost may be considerable when it is realized that high temperature alloy material must largely be employed in the construction of modern superheaters which are expected to heat steam to temperatures as high as 1250° F. or higher.

In Fig. 1A our invention is shown to be applied to a power plant in which the steam heaters 36, 42 and 30 are

arranged in a different order with respect to direction of gas flow. Thus the gases after leaving the furnace chamber **10** first pass over reheater **42**, then final stage or second stage superheater **36** and then finally over the heating surface of first stage superheater **30**. The steam flows through the various steam heaters and turbine stages in the same order as earlier described in connection with Fig. 1. Also, the temperature of the superheated steam and that of the reheated steam in a steam boiler arranged in accordance with Fig. 1A is, in accordance with our invention, independently controlled in the same manner as that earlier described herein in connection with Figs. 2, 3 and 4.

While an illustrative embodiment of our invention has been here shown and described, it will be understood that changes in construction, combination and arrangement of parts may be made without departing from the spirit and scope of the invention as claimed.

We claim:

1. In a steam generator having a furnace chamber for burning fuel including a furnace offtake for discharging a stream of combustion gases therefrom and a gas pass adjoining said offtake for receiving said gases, the walls of said furnace chamber being lined with fluid cooled tubes, a reheater, a final stage superheater section, and a first stage superheater section arranged in said gas stream in a downstream direction in the order named; the combination of first means for recirculating gas from the downstream side of the first stage superheater into the furnace chamber at a point remote from the outlet end thereof, whereby to decrease the gas temperature and the amount of heat absorbed by said fluid cooled tubes and correspondingly increase the temperature of the gases entering said reheater and the temperature of the reheated steam and thereby also increase perforce the temperature of the superheated steam; and second means for recirculating gas from the downstream side of said first stage superheater into the space between the reheater and the first stage superheater, thereby to finally control the temperature of the superheated steam independently of the temperature of the reheated steam by lowering the temperature of the steam leaving said first stage superheater section and entering said final stage superheater section.

2. In a steam generator having a furnace chamber for burning fuel including a furnace offtake for discharging the combustion gases therefrom and a gas pass adjoining said offtake for receiving said gases, the walls of said furnace chamber being lined with fluid cooled tubes, a final stage superheater section and a reheater serially arranged in said gas pass with respect to gas flow, and a first stage superheater section arranged in said gas pass on the downstream side of the reheater and final stage superheater; the combination of first means for recirculating gases from the downstream side of the first stage superheater into the furnace chamber at a point remote from the outlet end thereof and second means for recirculating gases from the downstream side of the first stage superheater into a space between the upstream side thereof and the reheater and first stage superheater, whereby to lower the gas temperature and the heat absorbed by said fluid cooled tubes and correspondingly increase the gas temperature entering said reheater and the temperature of the reheated steam and also increase thereby perforce the temperature of the superheated steam by the gases recirculated into the furnace chamber; and additionally to decrease the temperature of the superheated steam by the gases recirculated into said space on the upstream side of said first stage superheater.

3. In a steam generator having a furnace chamber for burning fuel including a furnace offtake for discharging a stream of combustion gases therefrom and a gas pass adjoining said offtake for receiving said gases, the walls of said furnace chamber being lined with fluid cooled tubes; a second stage superheater section, a reheater and a first stage superheater section arranged in the order named in said gas pass in a downstream direction; the combination of first means for recirculating gas from the downstream side of the first stage superheater into the furnace chamber at a point remote from the outlet end thereof, and ahead of said reheater with respect to gas flow whereby to reduce the gas temperature and the heat absorbed by said fluid cooled tubes and correspondingly increase the temperature of the gases entering said reheater and said reheated steam and thereby also increase perforce the temperature of the superheated steam; second means for recirculating gas from the downstream side of the first stage superheater into the space between the reheater and the first stage superheater; and means for by-passing gas around the reheater, whereby to control the temperature of the superheated steam independently of the temperature of the reheated steam by increasing the temperature of the steam leaving said first stage superheater section and entering said final stage superheater section.

4. In a steam generator having a furnace chamber for burning fuel including a furnace offtake for discharging a stream of combustion gases therefrom and a gas pass adjoining said offtake for receiving said gases the walls of said furnace chamber being lined with fluid cooled tubes; a reheater, a final stage superheater section and a first stage superheater section arranged in the order named in said gas pass in a downstream direction the combination of first means for recirculating gas from the downstream side of the first stage superheater into the furnace chamber at a point remote from the outlet end thereof, and at a point upstream of said reheater with respect to gas flow whereby to reduce the gas temperature and the amount of heat absorbed by said fluid cooled tubes and correspondingly increase the temperature of the gases entering said reheater and of the reheated steam and thereby also increase perforce the temperature of the superheated steam; second means for recirculating gas from the downstream side of said first stage superheater into the space between the reheater and the first stage superheater; and means for by-passing gas around the reheater whereby to control the temperature of the superheated steam independently of the temperature of the reheated steam by increasing the temperature of the steam leaving said first stage superheater and entering said final stage superheater.

5. In a steam generator having a furnace chamber for burning fuel including a furnace offtake for discharging the combustion gases therefrom and a gas pass adjoining said offtake for receiving said gases, the walls of said furnace chamber being lined with fluid cooled tubes; a final stage superheater section and a reheater arranged in said gas pass on the downstream side of said gas offtake, and a first stage superheater section arranged in said gas pass on the downward side of said reheater; the combination of first means for flowing gases from the downstream side of the first stage superheater into the furnace chamber at a point remote from the outlet end thereof and ahead of said reheater with respect to gas flow; second means for flowing gases from the downstream side of the first stage superheater into the space between the reheater and the first stage superheater and means for by-passing combustion gases around said reheater, whereby to reduce the temperature of the gases and the heat absorbed by said fluid cooled tubes and correspondingly increase the temperature of the gases entering said reheater and the temperature of the reheated steam and also increase the temperature of the superheated steam by said first flowing means of gases into the furnace chamber, and additionally and finally decrease or increase respectively the temperature of the superheated steam by said second flowing means or by-passing of gases into said space between the reheater and the first stage superheater.

6. In a vapor generating and heating unit having a furnace chamber for burning fuel and having means for

conducting the combustion gases out of and away from said chamber, the walls of said furnace chamber being lined with fluid cooled tubes; two separate high temperature vapor heaters serially arranged with respect to gas flow within said gas conducting means; a low temperature vapor heater supplying vapor directly to one of said high temperature vapor heaters and arranged on the downstream side of said high temperature heaters; the combination of first means for recirculating low temperature gases from the downstream side of said low temperature vapor heater into the furnace chamber at a point remote from the outlet end thereof and at a point upstream of the other of said high temperature vapor heaters; second means for recirculating gases of low temperature from the downstream side of said low temperature vapor heater into the space between said high temperature heaters and said low temperature heater; and means for by-passing gases from the furnace chamber directly around other of said high temperature heaters; whereby to reduce the gas temperature of the heat absorbed by said fluid cooled tubes and correspondingly increase the temperature of the gas flowing over said high temperature vapor heaters and the temperature of the vapor flowing out of said other high temperature heater and also the temperature of the vapor flowing out of said one high temperature heater by recirculating said gases into the furnace chamber, and to additionally decrease or increase respectively the temperature of the vapor leaving said one high temperature vapor heater by recirculating or by-passing gases into said space between said high temperature heaters and said low temperature heater.

7. The method of generating and heating steam which comprises producing a stream of gases by burning fuel in a combustion zone for any given rate of operation; flowing said stream in heat exchange relationship with steam generating means; thereafter flowing said stream in heat exchange relationship with first superheating means supplied with steam partially superheated by second superheating means; thereafter flowing said stream in heat-exchange relationship with steam reheating means; thereafter flowing said stream in heat exchange relationship with said second superheating means receiving steam from said steam generating means; controlling the rate of steam generation by varying the rate of fuel burned in said zone; raising and lowering the reheater outlet steam temperature by decreasing and increasing respectively the heat absorbed by said steam generating means from said stream through introducing a larger or smaller

amount of cooled combustion gases into said combustion zone and ahead of said reheater means with respect to gas flow direction; and controlling the first superheater outlet steam temperature by decreasing or increasing respectively the heat content of said stream at a location after having passed over said reheater means and before passing over said second superheating means through introducing into said stream at said location a quantity of cooler or hotter combustion gases respectively.

8. The method of generating and heating steam which comprises producing a stream of gases by burning fuel in a combustion zone for any given rate of operation; flowing said stream in heat exchange relationship with steam generating means; thereafter flowing said stream in heat exchange relationship with steam reheating means; thereafter flowing said stream in heat exchange relationship with first superheating means supplied with steam partially superheated by second superheating means; thereafter flowing said stream in heat exchange relationship with said second superheating means receiving steam from said steam generating means; controlling the rate of steam generation by varying the rate of fuel burned in said zone; raising and lowering the reheater outlet steam temperature by decreasing and increasing respectively the heat absorbed by said steam generating means from said stream through introducing a larger or smaller amount of combustion gases into said combustion zone and ahead of said reheater means with respect to gas flow direction; and raising or lowering the first superheater outlet steam temperature by decreasing or increasing respectively the heat content of said stream at a location after having passed over said reheater means and before passing over said second superheating means through introducing into said stream at said location a quantity of cooled recirculated gases or hot by-passed combustion gases respectively.

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