March 28, 1961 C. R. CHAN 2,976,858

METHOD OF AND APPARATUS FOR CONTROLLING SUPERHEAT AND REHEAT TEMPERATURES OVER A WIDE RANGE OF RATE OF STEAM GENERATION

Filed March 3, 1955 5 Sheets-Sheet 1

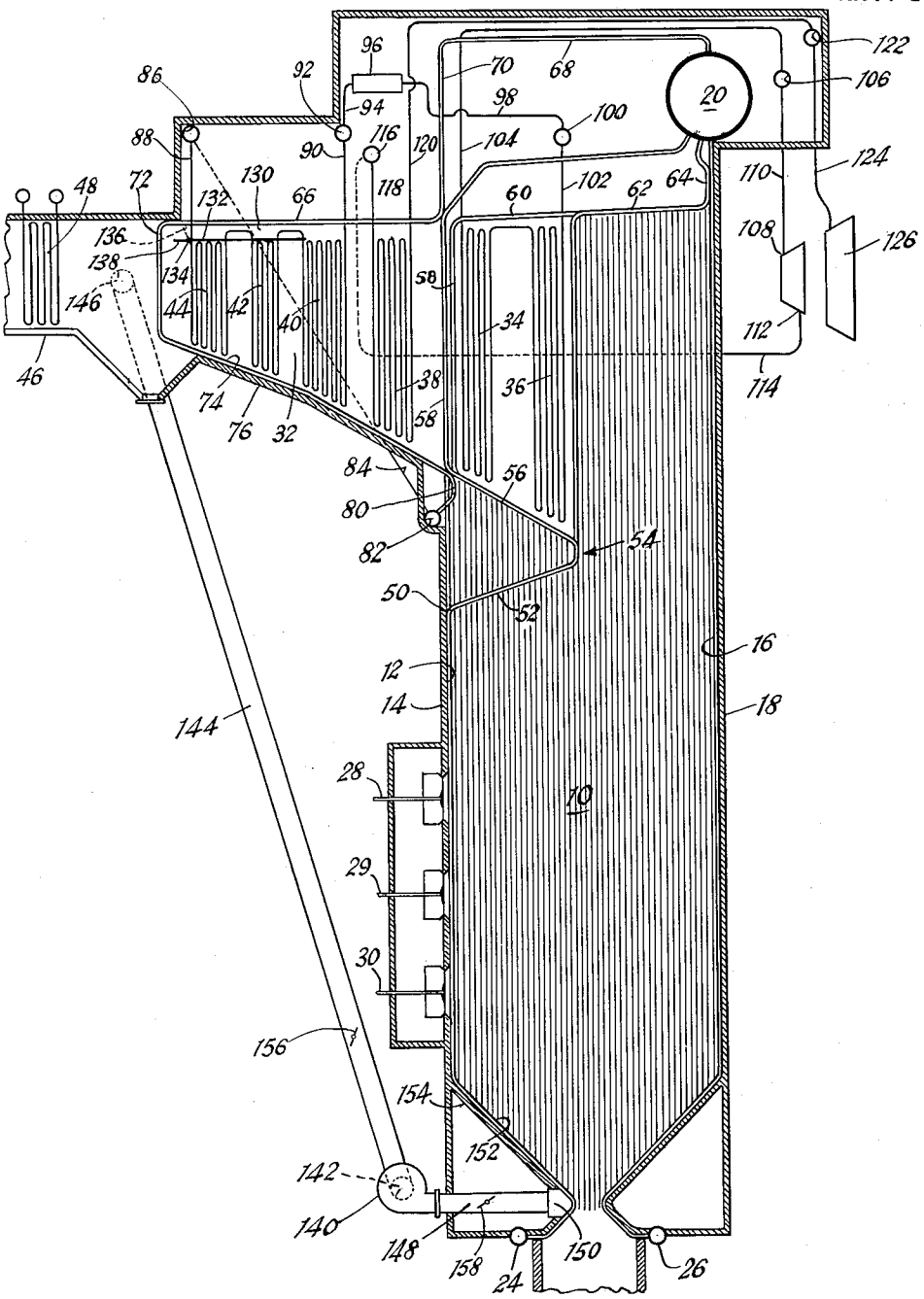


FIG. 1

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Filed March 3, 1955 5 Sheets-Sheet 2

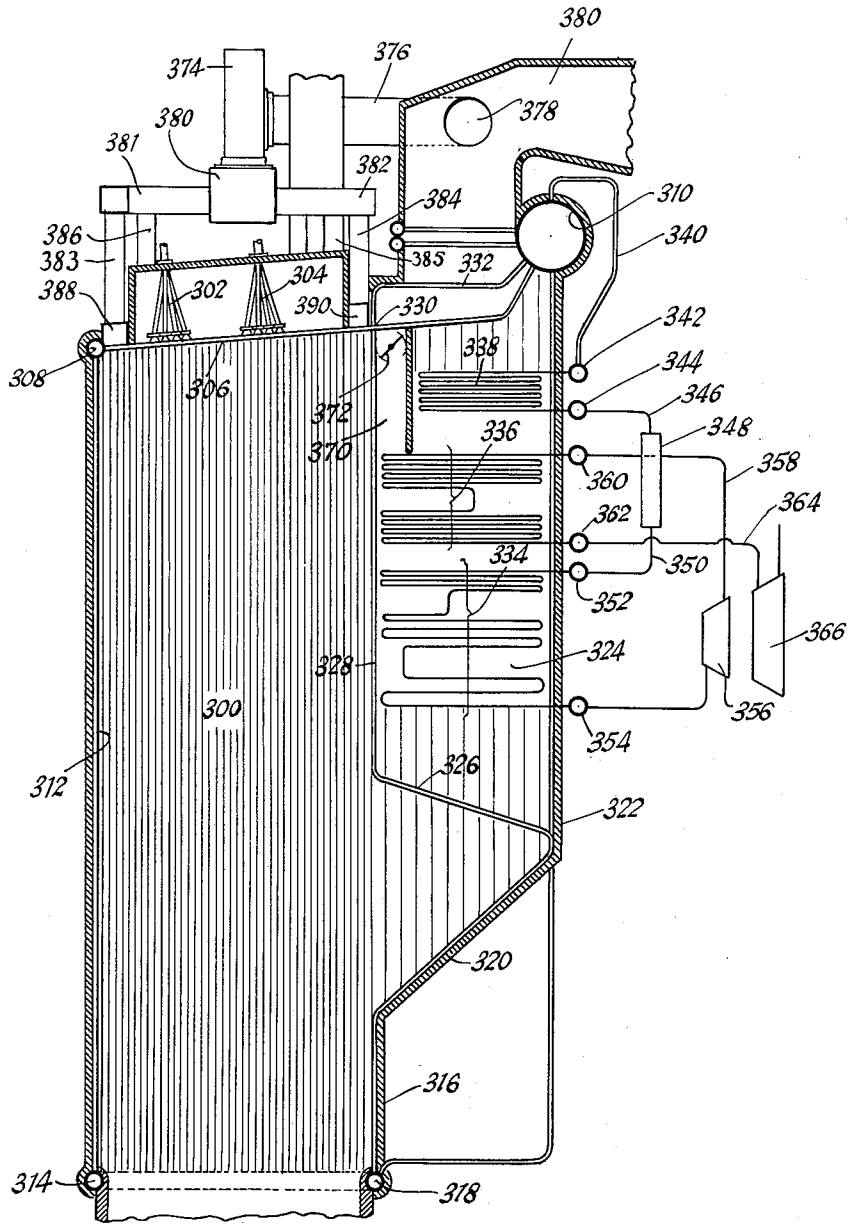


FIG. 2

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Filed March 3, 1955 5 Sheets-Sheet 3

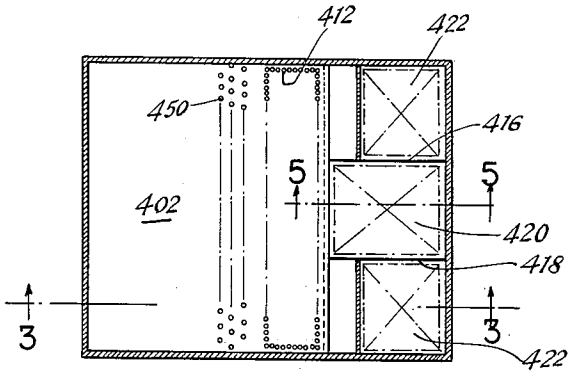


FIG. 4

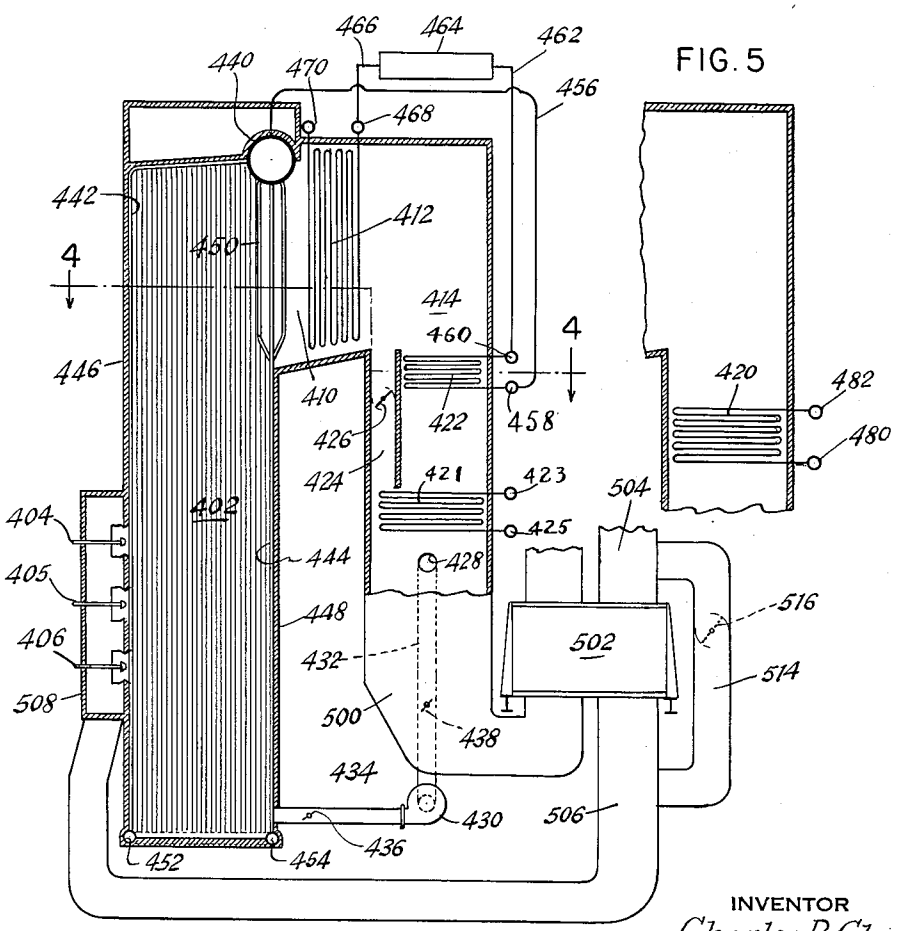


FIG. 5

FIG. 3

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Filed March 3, 1955 5 Sheets-Sheet 4

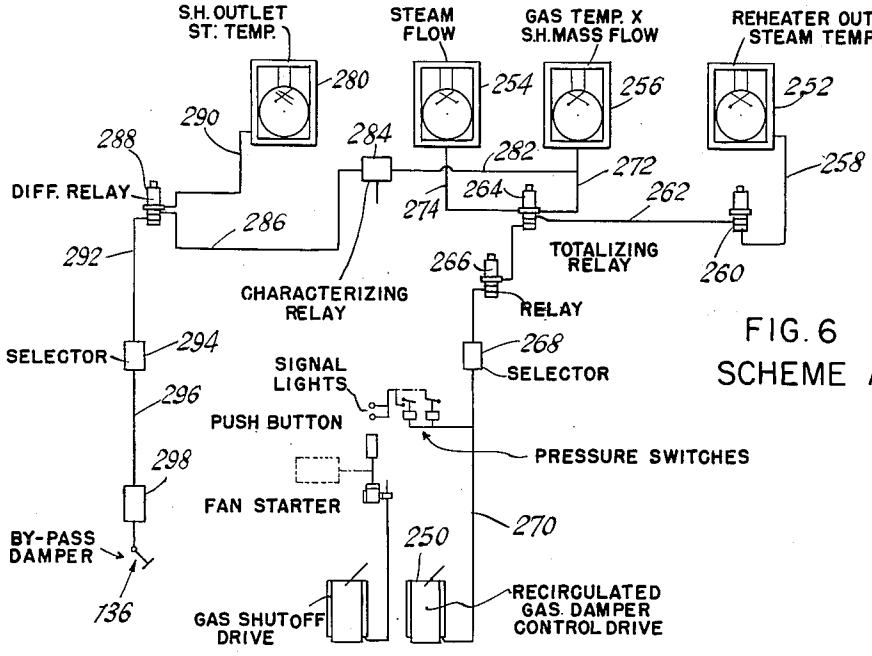


FIG. 6
SCHEME A

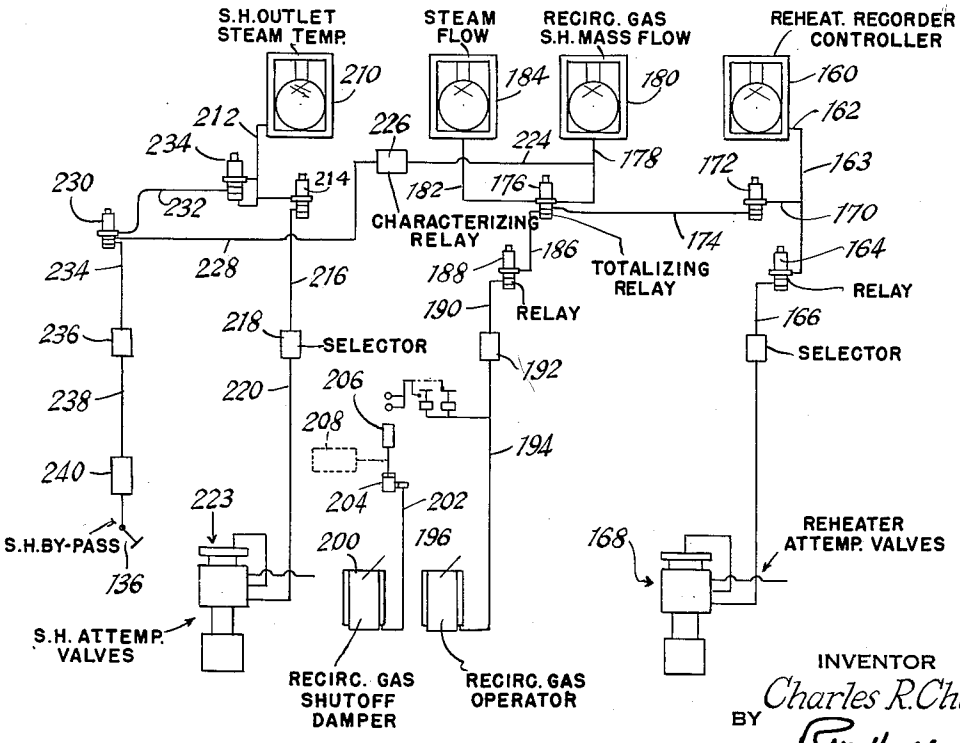


FIG. 7 SCHEME B

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FIG. 8

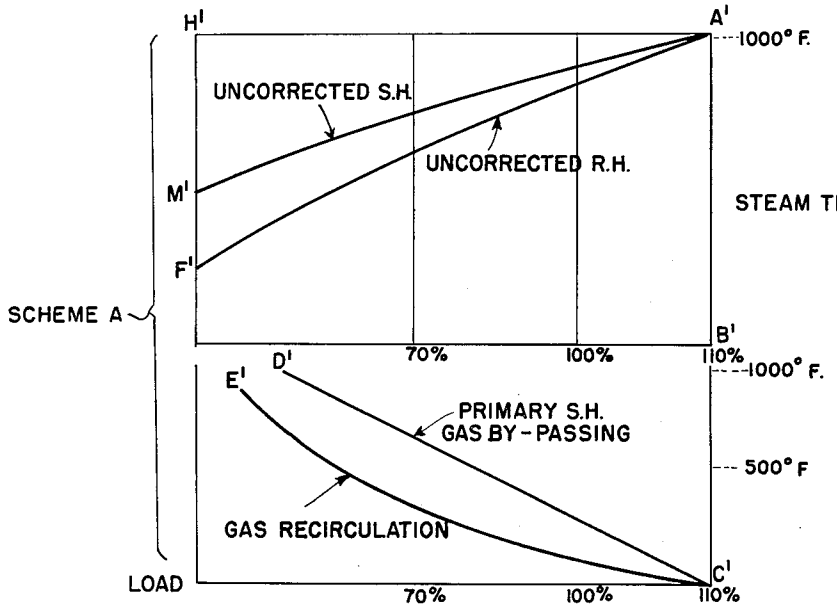
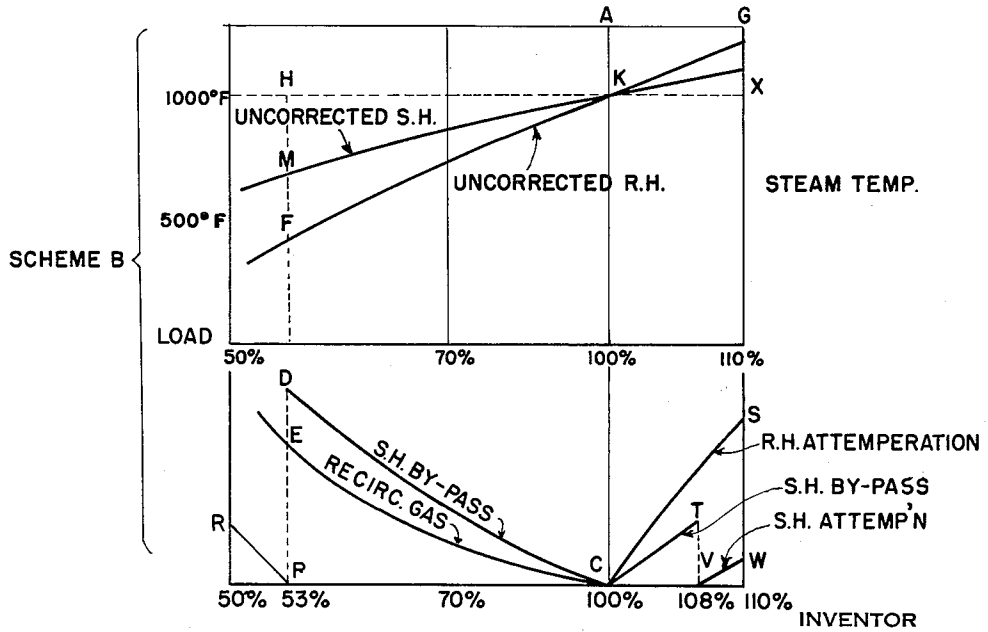


FIG. 9



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2,976,858

METHOD OF AND APPARATUS FOR CONTROLLING SUPERHEAT AND REHEAT TEMPERATURES OVER A WIDE RANGE OF RATE OF STEAM GENERATION

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Filed Mar. 3, 1955, Ser. No. 492,001

6 Claims. (Cl. 122—479)

This invention relates to methods of, and apparatus for, the control of high temperature vapor superheat and reheat, to maintain the superheat and reheat temperatures at a predetermined value, or predetermined values, over a wide range of rate of vapor generation.

More particularly, the invention involves the above indicated methods and apparatus wherein the vapor superheating and the vapor reheating take place in successive gas flow zones. In other words, the vapor superheating and the vapor reheating take place in series, from a gas flow standpoint.

The invention involves the superheating and the reheating of a high pressure vapor to a predetermined temperature, or predetermined temperatues, by the transmittal of heat from high temperature heating gases which have a proportion of their heat abstracted therefrom for the purpose of vapor generation before either the superheating zone or the reheating zone is reached. In the apparatus of the invention, the superheater and the reheater, arranged in series as to gas flow, are so set that design capacity, superheat temperature, and reheat temperature are attained at control point load without attemperation, without by-passing of vapor heating surface, and without gas recirculation. When the rate of vapor generation decreases from control point load to low load, in response to correspondingly decreased demand, the available heat in the gases for superheating and reheating is increased by an increasing rate of gas recirculation, to promote the maintenance of a predetermined superheat and reheat value, or values, over the indicated load range. Simultaneously with such control of available heat in the gases, an increasing proportion of the gases is by-passed around a low temperature section of the primary superheater only, as a result of the differential thermal requirements of superheat and reheat, under decreasing load. Thus, no attemperation is required as load changes from the control point load to low load; fan power is reduced due to decreased gas flow resistance, and temperature of the gases entering the air heater is increased considerably, requiring a minimum of air by-pass for the purpose of maintaining air heater metal temperatures within allowable limits.

At increasing load above the control point load, or during an overload range, reheat vapor temperatures are preferably controlled by attemperation, while the superheat temperature is simultaneously modified by an increasing amount of by-passing of the low temperature section of the superheating zone. At only very high overloads, beginning at a point considerably beyond the control point load, is superheat attemperation involved.

With the pertinent method, superheat and reheat control are effected from a control point load which may be indicated by 100% down to a low load value of 53% by a controlled and increasing amount of gas recirculation and by, simultaneously, a controlled and increasing amount of superheater by-passing. Over a very low load range, for example, below 53% of control point load there may be superheat attemperation, beyond the control ability of the superheater by-pass.

In the use of the illustrative method, the rate of flow of recirculated gases, and hence the control of available heat in the gases entering the superheating and the reheating zones, is controlled from indications of reheat temperature, and the control of the amount of gases by-passing the low temperature section of the superheater is controlled in accordance with variations in superheater outlet temperature. Other influences simultaneously effecting the control of gas recirculation and the control of by-passing may involve indications of vapor generating rate, as indicated by the flow of superheated vapor from the superheating zone. Such influences may also include the product of the gas temperature and the mass flow of gases across the superheater surfaces.

In illustrative apparatus for carrying out the invention, attemperators are preferably associated with both the superheater and the reheater, as safety devices, the operation of such attemperators being limited to an unusually low load or to overload, beyond the control point load.

The invention will be concisely and clearly set forth in the appended claims, but, for a complete understanding of the invention, its uses, and advantages, recourse should be had to the following description of preferred embodiments of the inventions, indicated in the accompanying drawings.

In the drawings:

Fig. 1 is a side sectional elevation of one type of high capacity and high pressure vapor generating, superheating, and reheating unit, constructed and arranged in accordance with the invention.

Fig. 2 is a view in the nature of a side elevation of a downfired vapor generating, superheating, and reheating unit to which the invention has been applied;

Fig. 3 is a diagrammatic view in the nature of a side elevation of a high pressure vapor generating, superheating, and reheating unit having a slag tap bottom, a recirculated gas system introducing the recirculated gases horizontally above the bottom and through the wall opposite the burners, and having a superheater and reheater arrangement wherein the reheater is arranged in one of two parallel passes, with the primary superheater in the other parallel pass, with a gas by-pass limited to the primary superheater only;

Fig. 4 is a dual level horizontal section on the line 4—4 of Fig. 3;

Fig. 5 is a fragmentary vertical section (on line 5—5 Fig. 4) of the reheater pass of the unit otherwise illustrated in Figs. 3 and 4;

Fig. 6 is a diagram illustrating an automatic control system for the automatic control of the flow of recirculated gas and the automatic control of the primary superheater by-pass;

Fig. 7 is a control diagram illustrating automatic control for the recirculated gas flow, the flow of gases through the superheater gas by-pass, and the amount of reheater attemperation;

Fig. 8 is a composite diagram showing curves illustrating the superheat and reheat temperatures in event that none of the illustrated control components are applied thereto, and illustrating the changes in gas by-passing of the primary superheater and the changes in gas recirculation, as the vapor generating load drops from a control point indicated as 110% of load; and

Fig. 9 is a composite diagram illustrating the operation of an apparatus with the superheater and reheater set to give predetermined vapor temperatures at an intermediate load position indicated as 100%, and showing the relative increase of superheat by-passing and recirculated gas flow from 100% load down to a load of ap-

proximately 53%. Below 53% of control point load, this diagram illustrates the rate of application of the superheat attemperation for loads below the capacity of the by-pass. Above 100% load this diagram indicates the rate of increase of reheat attemperation, the simultaneous rate of increase of superheat by-passing through about ⅔ of the load range from 100% to 110%, and the use of superheat attemperation in the remaining ⅓ of the load range between 100% and 110%.

Fig. 1 of the drawings shows a vertically elongated combustion chamber **10**, preferably of rectangular cross-section with its walls including upright vapor generating tubes, such as the tubes **12** along the front burner wall **14**, and the tubes **16** along the rear wall **18**. These vapor generating tubes are appropriately connected into a natural circulation circuit with the upper ends of the tubes discharging vapor and liquid mixtures into vapor and liquid separating apparatus within the vapor and liquid drum **20**. The separated liquid flows from its space within the drum **20** through appropriate downcomers (not shown) to lower drums or headers, such as those indicated at **24** and **26**, to which the lower ends of the vapor generating wall tubes are connected.

A furnace or combustion chamber **10** is fired by burners **28—30**, with the burners preferably disposed in a plurality of vertically spaced horizontal rows at the lower part of the combustion chamber, and along the wall **14**. The combustion gases exit laterally of the combustion chamber **10** at its upper portion through a convection gas pass **32**, wherein the gases pass, in succession, over a secondary superheater including the banks of tubes **34** and **36**, a reheater including the bank of tubes **38**, and a primary superheater including the successive banks of tubes **40**, **42** and **44**. After passing over the economizer **48** in the flue **46**, the gases pass over an air heater (not shown) which preferably has associated therewith an air by-pass for controllably by-passing air around the heating surfaces of the air heater.

Some of the vapor generating wall tubes **12** are bent at the position indicated at **50** out of their wall alignment to extend in a horizontally inclined arrangement toward the combustion chamber wall **18** as indicated at **52**. At this position these portions of the wall tubes form the lower surface of an arch **54**. The upper surface of this arch is defined by reversing the bent portions of the same wall tubes, these reversely bent portions **56** also defining a part of the inclined floor of the convection gas pass **32**. At the upper ends of the inclined tubular portions **56**, these tubes continue vertically through the tubular portions **58** which are widely spaced to permit the gases to flow freely through the gas pass. Beyond the upper ends of the tubular portions **58**, the pertinent vapor generating tubes extend along the portion **60** of the roof of the gas pass, and then along the portion **62** of the roof of the combustion chamber **10** to points adjacent the combustion chamber wall **18**. Thence the tubes extend upwardly as indicated at **64** to connections with the vapor and liquid mixture space of the drum **20**. The remaining portion **66** of the roof of the gas pass **32** includes superheater supply tubes **68** leading from the separated vapor space of the drum **20** horizontally to a position adjacent the plane in the wall **14**, then downwardly as indicated at **70** to a point adjacent the upper ends of the screen tube portions **58**, and then substantially horizontally to the left along the roof of the gas pass. Just to the rear of the tube bank **44** of the primary superheater the superheater supply tubes have widely spaced upright portions **72** joined at their lower ends to the inclined portions **74**, which lead in downwardly inclined arrangement along the sloping wall **76** of the convection gas pass. At a position near the plane of the wall **14** these supply tubes have downwardly extending portions **80** connected to the intermediate superheater header **82**. From this header the superheated steam flows through an appropriate connection **84** to the primary superheater inlet header **86**, and thence through the inlet connections **88** to the series connected tubes forming the banks of tubes **44**, **42** and **40** of the primary superheater. Thence the superheated steam flows through the outlet tubes **90** to the primary superheater outlet header **92**.

From the outlet header **92** of the primary superheater, the steam flows through a line **94** to and through the attemperator **96**, which is preferably a spray attemperator of the type indicated in the Fletcher and Huge Patent 2,550,683 of May 1, 1951.

From the attemperator **96** the superheated vapor or steam flows through one or more lines **98** to the inlet header **100** of the secondary superheater. From this header the superheated vapor flows through the inlet tubes **102** and thence to the serially connected return bend tubes constituting the banks of tubes **36** and **34** of the secondary superheater. From the secondary superheater the superheated vapor flows through the lines **104** to an outlet header **106**, and thence to the inlet **108** of a high pressure stage of a steam turbine, through the lines **110**.

From the outlet **112** of the high pressure turbine stage **108**, the expanded and lower pressure vapor flows through one or more lines **114** to the inlet header **116** of the reheater **38**. The vapor to be reheated flows through the inlet tubes **118** to the serially connected return bend tubes constituting the bank of tubes **38** of the reheater. After being reheated the vapor flows from the reheater through its outlet lines **120** to a reheater outlet header **122**, and thence through one or more lines **124** to the inlet of a low pressure stage **126** of the prime mover.

An attemperator, similar to the attemperator **96** may be interposed in the line **120**, for attemperating reheated steam.

As a part of the provisions for the control of superheat and reheat temperatures as the rate of vapor generation changes as a result of changes in the rate of firing in the burners **28—30**, the Fig. 1 unit includes a gas by-pass **130** formed between a horizontal baffle **132** extending across the tops of the banks of primary superheater tubes **42** and **44**, and the walls and roof of the convection gas pass. This gas by-pass around the first two banks of tubes of the primary superheater has its gas flow subject to control by a damper pivoted at **134** and movable automatically from the closed position **136** to its open position **138**.

As another part of the control provisions for maintaining a predetermined temperature of reheated vapor as the vapor generating load recedes from a control point load, which may be indicated as 100%, to a low load value of approximately 53%, the Fig. 1 unit includes a gas recirculation system. This system involves a fan **140**, the inlet **142** of which communicates by means of a duct **144** with an opening **146** in free communication with the heating gas flow beyond the primary superheater. The outlet of the fan **140** is connected by ductwork **148** to a transverse gas flow distributing chamber **150**, having at its right hand side a plurality of openings comunicating with openings between the tubular sections **152** of the vapor generating tubes extending along the wall **154** of the hopper bottom of the unit. The flow of recirculated gases may be controlled by one or more dampers, such as the dampers **156** and **158**, and/or by control of the speed of the fan **140**. As the rate of vapor generation decreases from a load value of 100% to a low load value of the order of 53%, the flow of gases through the recirculated gas system is increased so that the increased mass flow of gases over the reheater **38** will cause a sufficient increase in heat absorption by the reheater to maintain the temperature of the reheated vapor at the outlet of the reheater at a predetermined value.

The control system of Fig. 7 includes a reheater outlet vapor temperature recorder controller **160** appropriately connected to the reheater outlet line **120**, or **124**, and functioning to discharge varying loading impulses to the pneumatic line **162—163**, and thence to the input

side of the relay 164. The output loading impulses of the relay 164 are transmitted through line 166 to the valve operating mechanism 168 for the valve controlling the amount of spray liquid for the reheat attemperator.

The pneumatic loading impulses in the line 163—162 leading from the recorder controller 160 to the relay 164 are also communicated by the branch line 170 as a control input to the relay 172. The output load impulses of the relay 172 are communicated by the control line 174 to the input side of a totalizing relay 176. Another input position of the relay 176 receives loading impulses through the line 178 which are representative of changes in the product of recirculated gas temperature and superheater mass flow from the instrumentality 180. Another input position of the relay 176 is subject to the varying load impulses communicated thereto through the line 182 from the steam flow recorder-controller 184. Thus, the output impulses from the totalizing relay 176 passing through the outlet line 186 are subject to changes in the reheated steam temperature, changes in steam flow, or load, and subject to changes in the product of recirculated gas temperature and superheater mass flow. The totalizing relay 176 may be set so that anyone of the three incoming influences may be a predominating influence, for example, the variations in the temperature of the reheated steam from the recorder controller 160.

The combined control influences passing through the line 186 from the totalizing relay 176 are further subject to modification control by the relay 188. The outgoing impulses from this relay pass through the line 190, the manual-automatic selector 192, and the line 194 to the damper operator 196 which controllably varies the flow of recirculated gas by controlling the operation of the damper 156. The shut-off damper 158 for the recirculated gas system may be subject to control of the damper operator 200, which is controlled by control impulses passing thereto through the line 202 from a three-way solenoid valve 204. This solenoid valve is connected to the push button station 206, associated with the fan starter 208.

The superheater outlet vapor temperature recorder-controller 210, appropriately connected to the outlet line leading from the secondary superheater transmits pneumatic control impulses through the line 212, which are representative of changes in the superheater outlet vapor temperature. These impulses are transmitted to the relay 214, and thence modified as desired, through the line 216, the manual-automatic selector valve 218 and the line 220 to the valve operator 223 which is operatively connected to the valve controlling the flow of spray liquid to the superheater attemperator.

The flow of gases through the superheater by-pass 130 is subject to control by the control impulses of the output of the recorder controller 210 and the instrumentality 180. Control pulses from the latter pass through the branch line 224, the characterizing relay 226 and the line 228 to the differential relay 230. Another position on the input side of the relay 230 is connected by the line 232 leading from the output side of the relay 234. The output control pulses from the relay 230 pass through the line 234, the manual-automatic selector valve 236, and the line 238 to the damper operator 240 for gas flow regulator 136.

The relays of the Fig. 7 control system (and the Fig. 6 system) may be of the type shown by the U.S. patent to Dickey 2,098,913 or the U.S. patent to Gorrie—Re. 21,804. The selector valves of the system are of the type shown by the U.S. patent to Fitch 2,202,485. The steam temperature recorder-controllers 160 and 210 may be of the type shown by the U.S. patent to Wheaton 2,155,986, each operating a pilot valve of the type shown by the U.S. patent to Johnson 2,054,464. The steam flow recorder-controller 184 may be of the type shown by the U.S. patent to Ledoux 1,064,748.

By way of further explanation of the operation of the unit of Fig. 1, together with its control provisions, reference is made to Fig. 9. Here the line A, K, C indicates the control point load at which the superheater and reheater are set to give a predetermined superheat temperature and reheat temperature, or temperatures, without gas recirculation and without superheater by-passing. This control point load is also designated as 100% load. As the load, or rate of vapor generation decreases from 100% to about 53% the superheater by-pass damper is opened more widely by the control mechanism so as to effect an increased flow of by-passing gases through the by-pass as indicated by the line C—D of Fig. 9. Simultaneously, the flow of recirculated gas is increased by gradually opening the damper 156 or appropriately increasing the speed of the fan 140 to maintain the reheat temperature at a desired value. This increase in recirculated gas flow as the rate of vapor generation decreases from 100% to 53% is indicated by the line C, E of Fig. 9.

The upper part of Fig. 9 indicates, by the curve or line F, G the reheat temperatures which would be obtained if there were no control influences such as those herein described. In this part of the figure the line H—K indicates the constant value (for example 1000° Fahrenheit) at which reheat temperature and superheat temperatures are maintained by the illustrative control provisions. Thus, in this upper part of Fig. 9 the area H, F, K, may be said to indicate the extent of the control influence exercised by the recirculated gas flow upon reheat. Similarly the area K, M, H may be said to indicate the extent of a correction of superheat control effected by the combination of recirculated gas flow and the superheater gas by-pass.

Below a load value of approximately 53% as indicated by the line P—R of Fig. 9 superheat attemperation may be employed at an increasing rate as indicated by the curve or line R—P. Such attemperation takes place at loads below the ability of the superheater by-pass to effect the desired control.

At overloads or loads from the control point load of 100% to 110%, an increasing amount of reheat attemperation takes place as indicated by the line C—S of Fig. 9. Simultaneously through the first part of this overload range superheat by-passing is also effective in an increasing degree as indicated by the line C—T of Fig. 9. Further control at the extreme overload of 108% to 110% is provided by increasing the superheat attemperation, as indicated by the line V—W.

The net amount of correction upon reheat above the control point load of 100% may be said to be indicated by the area XKG.

In the control method indicated by Fig. 8 the superheater and the reheater are set to effect the desired reheat and superheat vapor temperature or temperatures at a full load indicated as 110% load. This is also indicated by the line A'B', in Fig. 8. As the rate of vapor generation decreases from 110% load down to some load value in the neighborhood of 60% load, the flow of recirculated gases is increased as indicated by the line or curve C'E', of Fig. 8. Simultaneously, the flow of gases through the primary superheater by-pass is gradually increased as indicated by the curve C'D'. The extent of the corrective influences upon superheat is indicated by the area A'M'H' in Fig. 8 and, similarly, the extent of the corrective influences exerted upon reheat is indicated by the area A'F'H'.

The control system of Fig. 6 is somewhat similar to that of Fig. 7 with the general exception that the Fig. 6 system does not include any control of attemperator valves. In the Fig. 6 system the damper operator 250 controls the flow of recirculated gases, and the control of operator 250 is exercised from control impulses originating in the reheater outlet vapor temperature recorder-controller 252, the steam flow recorder-controller 254, and the instrumentality 256 for recording changes in the

product of recirculated gas temperature times superheater mass flow. Controlled and modified pneumatic impulses pass from the reheater outlet steam temperature recorder-controller through the line 258, the relay 260, the line 262, the totalizing relay 264, the relay 266, the manual-automatic selector valve 268 and the line 270 to the recirculated gas damper operator 250.

The control impulses passing through the line 262 from the relay 260 are modified by control impulses passing respectively from the steam flow recorder-controller 254 and the instrumentality 256, in the totalizing relay 264. This relay is also connected to the output of the instrumentality 256 (which indicates changes in the product of recirculated gas temperature and superheater mass flow) by the line 272, and the input side of the relay 264 is also connected to the recorder-controller 254 by the line 274. The superheater by-pass damper 136 is operated by the combined effects of control influences from the superheater outlet vapor temperature recorder-controller 280, and the instrumentality 256. The output impulses from the latter instrumentality pass through the line 282, the characterizing relay 284 and the line 286 to the differential relay 288, which also receives control impulses through the line 290 leading from the recorder-controller 280. The impulses outgoing from the differential relay 288 are transmitted through the line 292, the manual-automatic selector valve 294 and the line 296 to the damper operator 298.

The Fig. 2 steam generating, superheating, and reheating unit includes a combustion chamber which is downfired by groups of fuel burners 302 and 304 which project fuel and air streams through openings between spaced roof tubes 306. These tubes lead from the upper header 308 to the drum 310, conducting steam and water mixtures to the drum from the outlets of the vapor generating wall tubes 312 extending from the lower header 314 to the header 308. Along the opposite wall 316 of the combustion chamber 300 other vapor generating wall tubes lead upwardly from the lower header 318 to the upwardly inclined wall 320 along which parts of these tubes extend to the rear wall 322 of the upflow convection gas pass 324. Successive parts 326 of these tubes act as screen tubes extending in upwardly inclined relation across the gas entrance of the gas pass 324 to the furnace wall 328 which separates the gas pass 324 from the combustion chamber 300. These tubes continue along the wall 328, pass through the roof of the unit at 330 and continue, in the sections 332 across the gas flow at the exit of the convection gas pass, to the drum 310.

The upwardly flowing gases in the gas pass 324 first pass over the convection bank of tubes constituting the secondary superheater 334, then over the banks of tubes constituting the reheater 336, and lastly over the bank of tubes constituting the primary superheater 338.

Steam separated from the steam and water mixtures entering the drum 310 passes through one or more lines 340 from the steam space of the drum 310 to the inlet header 342 of the primary superheater. Steam flows through the serially arranged return bend tubes of the primary superheater to the outlet header 344. From that header the steam flows through one or more lines 346 to and through the attemperator 348. From the attemperator the steam flows through one or more lines 350 to the inlet header 352 of the secondary superheater 334. From that header steam flows through the serially connected return bend tubes constituting the banks of tubes of the secondary superheater to the outlet header 354, and thence to the inlet of the high pressure turbine stage 356. From the outlet of this turbine stage steam flows through one or more lines 358 to the inlet header 360 of the reheater 336. From the outlet header 362 of the reheater steam flows through one or more lines 364 to the inlet of a second or low pressure stage 366 of the turbine.

The reheated steam circuit may include an attemperator similar to the attemperator 348 for the superheater circuit, and, like the Fig. 1 unit, the Fig. 2 unit discloses a primary superheater gas by-pass 370, the flow of gases through this by-pass being controlled by a damper 372 subject to such automatic regulation as that previously referred to in connection with the description of the Fig. 1 unit. The superheat and reheat attemperators are also subject to the automatic control, and the same is true of the gas recirculation system for the Fig. 2 unit. This system includes a recirculated gas fan 374 having its inlet connected by a duct 376 to an opening 378 in communication with the ductwork or breeching 380 acting as a part of the flue conducting the heating gases from the outlet of the convection gas pass 324. The outlet of the fan 374 is connected to distribution ducts such as 388 and 390 arranged along the walls of the combustion chamber 300, the ductwork components connecting the outlet of the fan to the distribution conduits 388 and 390 including the ductwork components 380—386. The distributing ducts 388 and 390 are provided with openings distributed along their lengths for conducting recirculated gas between the roof tubes 306 and projecting them along the adjacent walls of the combustion chamber 300.

The Fig. 2 unit would also include a convection economizer including a deep bank of spaced tubes distributed across the gas flow at a position downstream of the primary superheater 338 in a gas flow sense.

The side walls of the combustion chamber 300 include upright vapor generating tubes similar to those for the walls 312 and 316, connected at their upper and lower ends through appropriate headers and having other appropriate connections to the steam and water drum 310. Such connections for all of the lower headers of the unit, such as the headers 314 and 318 would include appropriate large diameter downcomers leading from the water space of the drum 310 to the lower headers.

In further reference to the Fig. 2 unit, it is to be understood that the recirculated gas system may have its ductwork components provided with appropriate dampers whereby the flow of recirculated gases to positions along the walls of the combustion chamber 300 may be regulated by an automatic control system, such as that previously described.

The vapor generating unit shown in Figs. 3, 4 and 5 has a combustion chamber 402, of a construction similar to the combustion chambers of the previously described units. The combustion chamber 402 is fired by horizontal rows of burners 404—406 from which combustion gases flow upwardly in the combustion chamber 402, and then laterally through the transverse gas pass 410 at the upper part of the unit. Within this gas pass is a bank of tubes constituting the secondary superheater 412. This bank of tubes extends entirely across the unit as indicated in Fig. 4. The lateral gas pass 410 is connected at its outlet with a downflow gas pass 414 which is divided into three parallel sub-passes by the parallel walls 416 and 418 (see Fig. 4). In the middle sub-pass there is arranged a convection reheater 420, each of the remaining sub-passes having like primary superheater sections 422. Each of these primary superheater sections is associated with its own gas by-pass such as 424 of Fig. 3, having its own damper 426 for controlling the flow of by-passing gases.

Disposed in the downflow gas pass 414 at a position beyond the primary superheater sections is the economizer 421 with its headers 423 and 425, and communicating with the gas flow just beyond the economizer is the inlet 428 of the gas recirculation system, including the fan 430, the inlet duct 432 and the fan outlet duct 434 leading to the lower part of the combustion chamber 402. The flow of recirculated gases through said system being controlled by the operation of appropriate dampers such as 436 and 438.

The Fig. 3 unit includes a steam and water drum 440

which, like the other steam and water drums of the other units, is provided with a plurality of cyclone steam and water separators such as that shown in the U.S. patent to Fletcher and Rowland 2,289,970, July 14, 1942. Communicating with the steam and water mixture chamber of the steam and water drum are the upper ends of vapor generating tubes, such as the combustion chamber wall tubes 442 and 444 extending along the opposite walls 446 and 448 of the combustion chamber 402, the upper ends of the vapor generating wall tubes 444 being preferably widely spaced to form the screen 450 of widely spaced tube portions extending across the gas flow from the upper part of the combustion chamber to the lateral gas pass 410.

It is to be understood that the remaining walls of the combustion chamber 402 similarly include vapor generating tubes, and that all of the vapor generating tubes are connected by appropriate headers and other connections into the natural circulation system, which includes the drum 440 and appropriate downcomers leading from the separated water space of the drum 440 to lower headers, such as the headers 452 and 454.

Separated steam flows from the steam space of the drum 440 through one or more conduits 456 to the inlet headers 458 of the primary superheater sections 422. From this header the steam flows in succession through the series connected return bend tubes constituting the banks of tubes of the primary superheater sections to the outlet headers 460. From these outlet headers steam flows through parallel lines 462 to the superheater attemperators 464, and thence through lines 466 to the inlet header 468 of the secondary superheater. From the outlet header 470 of the secondary superheater the steam flows to the inlet of a high pressure turbine, such as that indicated in connection with the description of the other steam generating units. From the outlet of this high pressure turbine stage the steam flows to the inlet header 480 of the bank of tubes constituting the convection reheater 420, disposed in the middle sub-pass into which the downflow convection gas pass 414 is divided by the partition walls 416 and 418. From the reheater outlet header 482 the reheated steam flows through appropriate lines to the inlet of the low pressure stage of the turbine.

For the maintenance of a predetermined superheated steam or vapor temperature, and a predetermined reheated vapor temperature over a wide load range, the Fig. 3 unit is controlled in the manner previously described so as to effect the method which is also previously referred to, the primary superheater by-pass dampers, the attemperators, and the controllable components of the gas flow recirculation system being automatically controlled by a control system such as that shown in Fig. 7.

It is contemplated that each of the Fig. 1, Fig. 2, and Fig. 3 vapor generating, superheating, and reheating units shall include an air heating system such as that diagrammatically illustrated with respect to the Fig. 3 unit. In this system the gases flow from the down-flow convection gas pass 414 through ductwork 500 to an air heater 502. The air heater has an air inlet 504 and an air outlet leading into the ductwork 506 leading, in turn, to the windbox 508, in which the burners 404 and 406 are disposed. Control of the metal temperatures of the air heater may be effected by the use of the air by-pass 514 leading from the air inlet 504 to the ductwork 506 as indicated in the drawing. The control of the by-passing air flowing through the ductwork 514 is effected by the damper 516. The method of the invention results in a 25° Fahrenheit rise in the gas temperature entering the air heater, and the air heater metal temperatures would therefore be higher. The method also results in a substantial reduction in the amount of air by-passed around the air heater for maintaining the air heater metal temperatures within allowable limits.

While in accordance with the provisions of the statutes I have illustrated and described herein a specific form of the invention now known to me, 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 my claims, and that certain features of the invention may sometimes be used to advantage without a corresponding use of other features.

What is claimed is:

1. In a vapor generating, superheating and reheating unit, means forming a fuel fired combustion chamber, means forming a convection gas pass leading from the gas outlet of said chamber, a secondary vapor superheater, a vapor reheater, and a primary vapor superheater arranged in the convection pass; means within the convection gas pass constituting a dampered gas by-pass around the primary superheater only; a gas recirculation system including a fan and dampered ductwork leading from an inlet positioned within the gas flow path beyond the primary superheater to an outlet positioned within the combustion chamber for withdrawing lower temperature gases from the inlet and introducing those gases into the combustion chamber; means for increasing the flow of recirculated gases in response to a reduction in reheated vapor temperature from a selected standard temperature as modified by an indication of a reduction in vapor generating rate and a reduction in the product of gas mass flow and gas temperature in said convection gas pass, and vice versa, the increased use of recirculated gas in sufficient quantity to maintain a desired reheated vapor temperature tending to raise the superheater vapor temperature above a selected desired value, and means for regulating the gas flow through said by-pass around said primary superheater to maintain the superheat temperature at a desired value, said regulating means operative to position the damper in an opening direction in said by-pass in response to increased superheat temperatures as modified by the product of gas mass flow and gas temperature in said convection pass.

2. In a vapor generating, superheating and reheating unit according to claim 1, wherein said secondary vapor superheater, vapor reheater and primary vapor superheater are arranged for sequential flow of heating gases thereover in the order named.

3. In a vapor generating, superheating and reheating unit according to claim 2, wherein said combustion chamber is upright and downfired by burner means positioned in the upper portion thereof, and said convection gas pass is upright and arranged for upflow of gases therethrough.

4. In a vapor generating, superheating and reheating unit according to claim 1, wherein said primary vapor superheater and vapor reheater are arranged for parallel flow of gases thereover, and said secondary vapor superheater is positioned upstream in a gas flow sense of said parallel arranged primary vapor superheater and said vapor reheater.

5. In a vapor generating, superheating and reheating unit, means forming a fuel fired combustion chamber, means forming a convection gas pass leading from the gas outlet of said chamber, a secondary vapor superheater, a vapor reheater, and a primary vapor superheater arranged in the convection pass; an attemperator positioned between the primary and secondary vapor superheaters in the vapor flow path therebetween, means within the convection gas pass constituting a dampered gas bypass around the primary superheater only; a gas recirculation system including a fan and dampered ductwork leading from an inlet positioned within the gas flow path beyond the primary superheater to an outlet positioned within the combustion chamber for withdrawing lower temperature gases from the inlet and introducing those gases into the combustion chamber; means for increasing the flow of recirculated gases in response to a reduction in reheated vapor temperature from a selected standard temperature as modified by an indication of a reduction in vapor generating rate and a reduction

in the product of gas mass flow and gas temperature in said convection gas pass, and vice versa, the increased use of recirculated gas in sufficient quantity to maintain desired reheated vapor temperatures tending to raise the superheated vapor temperature above a selected desired value, and means for regulating the gas flow through said bypass around said primary superheater to maintain the superheat temperature at a desired value, said regulating means operative to position the damper in an opening direction in said bypass in response to increased superheat temperatures as modified by the product of gas mass flow and gas temperature in said convection pass, said damper operative means being effective to actuate said attempterator with increased superheater temperatures only when said bypass damper is fully open.

6. In a vapor generating, superheating and reheating unit, means forming a fuel fired combustion chamber, means forming a convection gas pass leading from the gas outlet of said chamber, a secondary vapor superheater, a vapor reheater, and a primary vapor superheater arranged in the convection pass; means within the convection gas pass constituting a dampered gas bypass around the primary superheater only; a gas recirculation system including a fan and dampered ductwork leading from an inlet position within the gas flow path beyond the primary superheater to an outlet positioned within the combustion chamber for withdrawing lowered temperature gases from the inlet and introducing those gases into the combustion chamber; means for increasing the flow of recirculated gases in response to a reduction in reheated vapor temperature from a selected standard temperature as modified by an indication of a reduction in vapor

generating rate and a reduction in the product of gas mass flow and gas temperature in said convection gas pass, and vice versa, the increased use of recirculated gas in sufficient quantity to maintain desired reheated vapor temperatures tending to raise the superheated vapor temperature above a selected desired value, means for regulating the gas flow through said bypass around said primary superheater to maintain the superheat temperature at a desired value, said regulating means operative to position the damper in an opening direction in said bypass in response to increased superheat temperatures as modified by the product of gas mass flow and gas temperature in said convection pass, and spray attemperating means for separately cooling said super-heated and reheated vapors when said vapors exceed selected temperature values.

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