Jan. 14, 1958 P. H. KOCH 2,819,702

METHOD OF AND APPARATUS FOR CONTROLLING VAPOR TEMPERATURES

Filed Dec. 29, 1951 4 Sheets-Sheet 1

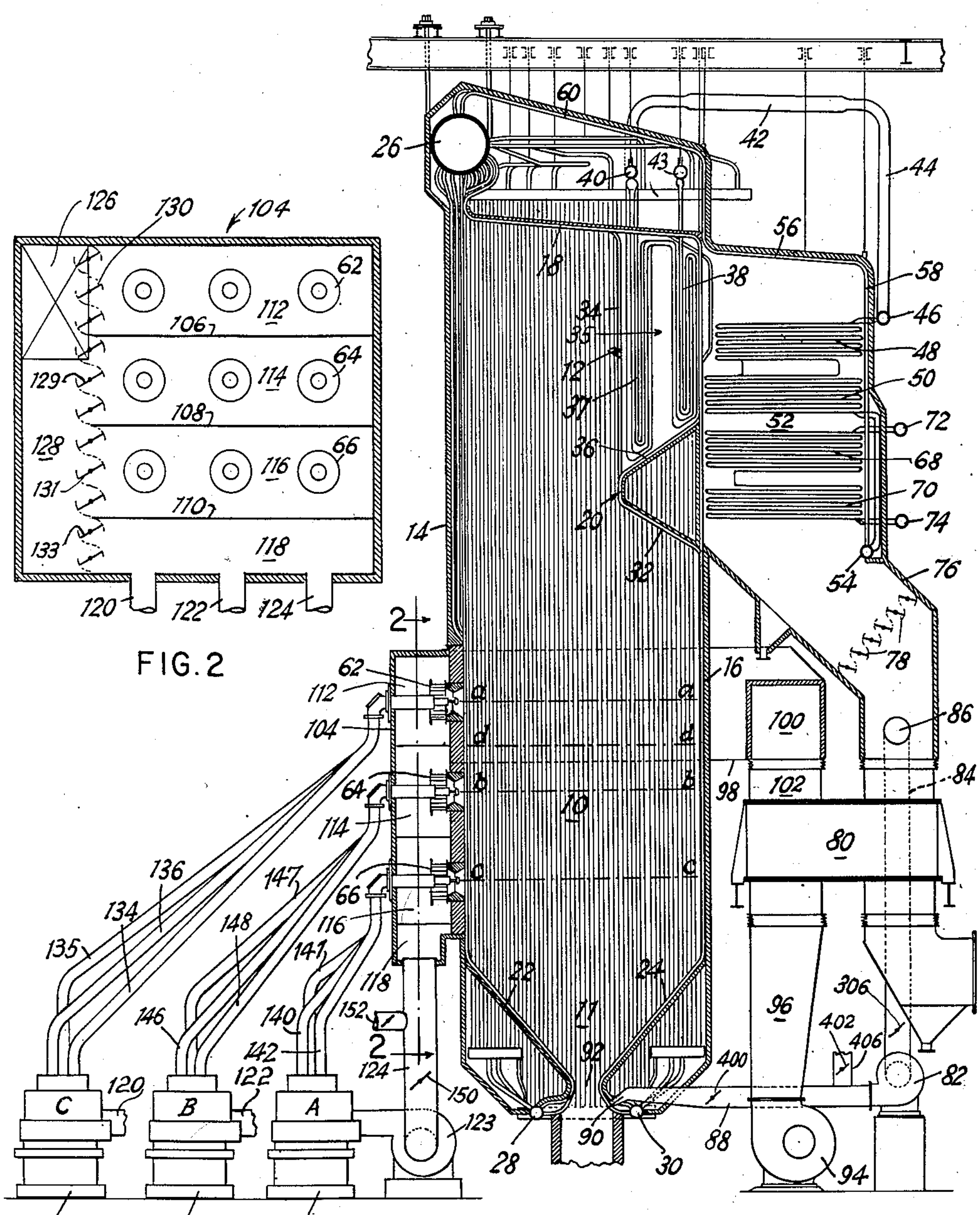

FIG. 2

FIG. 1

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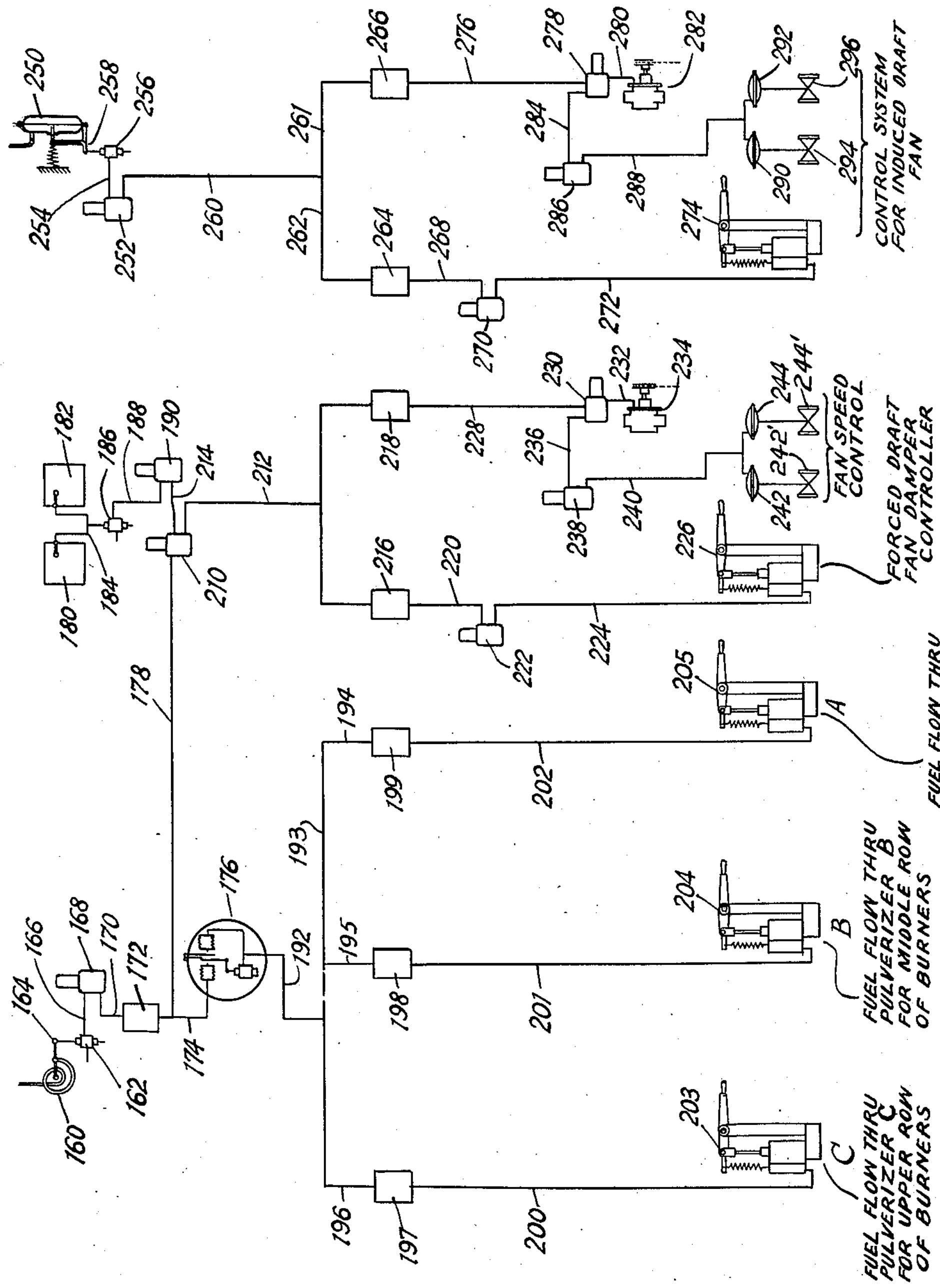

FIG. 3

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METHOD OF AND APPARATUS FOR CONTROLLING VAPOR TEMPERATURES

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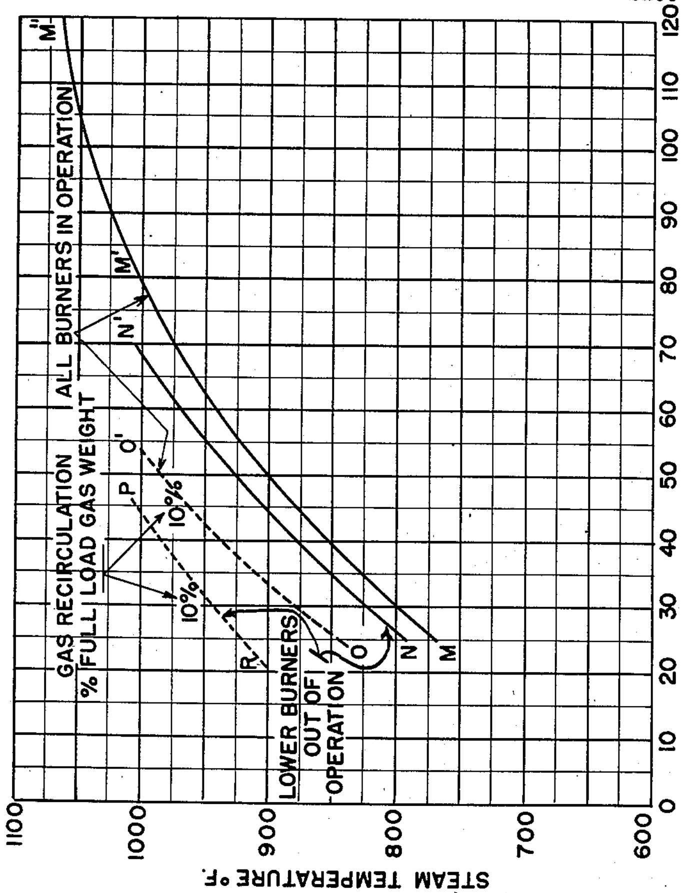

FIG. 5

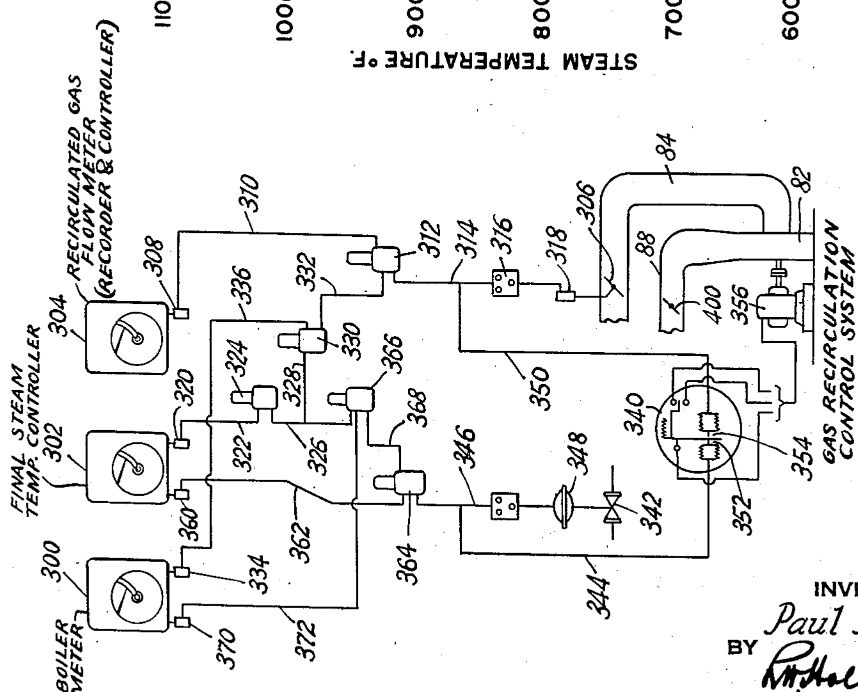

FIG. 4

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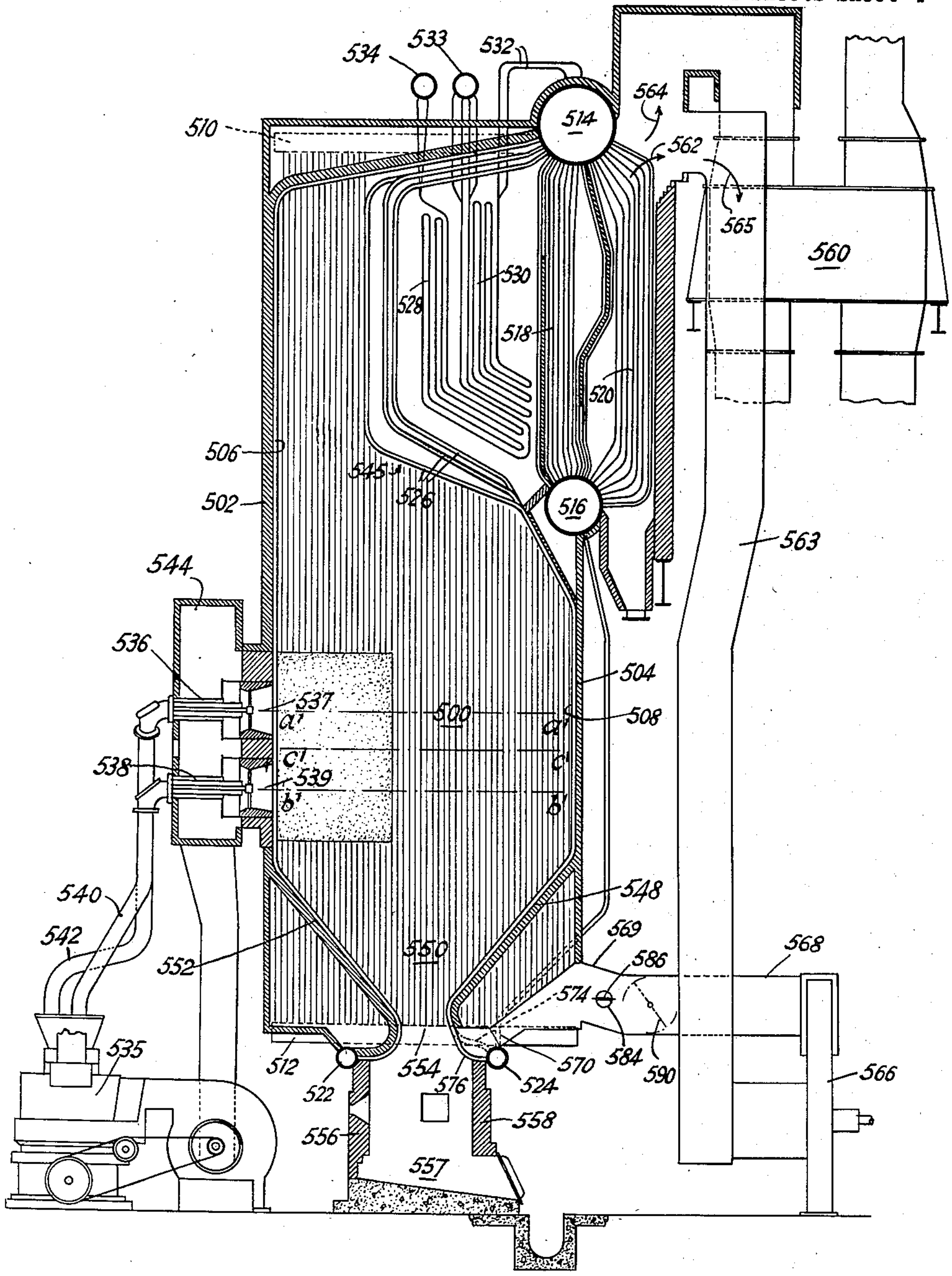

FIG. 6

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United States Patent Office

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METHOD OF AND APPARATUS FOR CONTROLLING VAPOR TEMPERATURES

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Application December 29, 1951, Serial No. 264,029

11 Claims. (Cl. 122—479)

This invention relates to improvements in methods of and apparatus for controlling vapor superheat temperature in vapor generating and vapor superheating units in which fuel is burned in suspension in a furnace having fluid cooled walls forming an appreciable portion of the total vapor generating surface of the unit. The vapor generated is superheated by its passage through tubular superheater elements heated mainly by convection heat transfer from the heating gases developed in the burning of the fuel as they flow from the furnace.

The convection superheating effect is dependent upon the temperature and the mass of the heating gases flowing over the superheater tubes and these factors in turn are dependent upon the combustion conditions in the furnace and the amount of heat transferred from the gases to the fluid cooled furnace walls while the fuel is being burned and while the heating gases flow to the furnace outlet. It is known that the heat transfer to such furnace walls can be varied by shifting the proximity or level of the main combustion zone relative to the furnace gas outlet and thereby control the temperature of the heating gases flowing over the superheater tubes and correspondingly control the convection superheating effect.

In my prior application Ser. No. 167,073, filed June 9, 1950 (now Patent 2,737,931, March 13, 1956), of which this application is a continuation-in-part, I have disclosed and claimed a method of and apparatus for vapor superheat control in which the radiant transfer of heat from the combustion zone and furnace gases to the fluid cooled furnace walls is varied by the introduction of heating gases from a position wholly or partly downstream of the superheater into the furnace in such a manner that a layer or stratum of relatively low temperature gas is interposed between the main combustion zone and a substantial portion of the fluid cooled furnace wall area to vary the radiant heat transfer to the vapor generating tubes of the walls and thereby control the heat content of the heating gases leaving the furnace and flowing over the superheater.

My present invention comprises a method of and apparatus for controlling vapor superheat temperatures in a unit of the character described which, in general, involves the concurrent use of heating gas recirculation and combustion zone level variation to obtain a range and degree of vapor superheat control which is greater than can be obtained by the use of either a corresponding amount of gas recirculation or a corresponding change in combustion zone level alone, or by the sum total of these individual effects.

In carrying out the method of the invention for the control of superheat in a steam generating unit having a vertically elongated fluid cooled furnace with a heating gas outlet from the upper portion thereof leading to a convection heated superheater, fuel and combustion air are introduced through a plurality of vertically spaced regulable burners or other controllable burner means in

a vertical furnace wall to burn a preponderance of the fuel in a main combustion zone having a mean level intermediate the height of the furnace, from which zone the heating gases flow to the furnace gas outlet and heat is radiated from the gases to the surrounding furnace wall steam generating tubes. The heat content of the gases leaving the furnace outlet is increased by introducing a controlled stream of recirculated gases into the lower portion of the furnace below the combustion zone level while concurrently varying the adjustment of the regulable fuel burners to effect a higher mean level of the main combustion zone.

The invention effects a reduction in draft loss, as compared to a method or apparatus accomplishing the same superheat control result by recirculating gases, but lacking the concurrent variation of level of the main combustion zone. The invention also minimizes or reduces fan and duct system cost, and reduces power required to operate the recirculating fan.

Various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification, but, for a better understanding of the invention, its operating advantages and the specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which preferred embodiments of the invention are described.

In the drawings:

Fig. 1 is a vertical sectional view of a vapor generating unit including the burner level control, attemperator, and gas recirculation system as components of the superheat control system of the invention;

Fig. 2 is a partial vertical section on the line **2—2** of Fig. 1, showing the arrangement of rows of burners and their communications with the wind-box or secondary air chamber;

Fig. 3 is a schematic drawing of a superheat control system for automatic operation of the unit shown in Fig. 1;

Fig. 4 is a similar schematic view of an additional part of the automatic control system for regulating the gas recirculation system for controlling superheat;

Fig. 5 is a chart with curves illustrating the increased load range over which steam temperature is maintained, and

Fig. 6 is a sectional elevation of a modified unit, embodying the invention.

The illustrative vapor generating and superheating unit shown in Fig. 1 includes a vertically elongated furnace **10** having a hopper bottom **11** and a furnace gas outlet **12** in the upper portion thereof. The furnace boundaries such as the burner wall **14**, the rear wall **16**, the side walls (one of which is shown facing the observer), the roof **18**, the arch **20**, and the hopper bottom walls **22** and **24**, are defined by vapor generating tubes having their upper ends in communication with the steam and water drum **26**. The lower ends of the tubes are connected to appropriate headers such as **28** and **30** which have connections with suitable downcomers, which, in turn, are connected to the liquid space of the drum **26**. The arch **20** below the gas outlet **12** is formed by a row of tubes **32**, bent out of the plane of the rear wall **16**, with some of these tubes extended upwardly from the nose of the arch to the roof as row **34** in which the tubes are more widely spaced than in the arch, providing a screen across the outlet from the furnace to the superheater chamber. The remaining tubes **36** in the arch row are inclined rearwardly to merge into and extend upwardly in the plane of the rear furnace wall.

The gas passage from the furnace gas outlet includes a horizontally extending passage **35** and a serially connected downwardly extending gas pass **52**. The convection superheater surface comprises a primary superheater section including a plurality of laterally spaced serially connected multiple loop elements **50** and **48** extending transversely of the gas pass **52**, and a secondary superheater including a plurality of laterally spaced serially connected multiple loop elements **37** and **38** pendently supported transversely of the passage **35**. The inlet header **54** of elements **50** is connected to the vapor space of the drum by serially connected tube lengths **56, 58**, and **60**, and the outlet header **46** of elements **48** is connected by conduit **44**, to the inlet header **40** of the secondary superheater, while the outlet ends of elements **38** are connected to the superheated steam outlet header **43** which in turn is connected by piping not shown to the steam user. The conduit **44** includes a section **42** which involves a spray attemperator of the type shown by Patent 2,550,683 to Fletcher et al., dated May 1, 1951.

An economizer consisting of a plurality of laterally spaced multiple loop elements **68** and **70** is positioned in pass **52** below the convection superheater. It has an inlet header **74** and an outlet header **72**, respectively, connected to a supply of feed water and to the water space of the drum **26**. A gas flue **76**, including dampers **78** connects pass **52** to the gas inlet of a regenerative air heater **80**, from which an appropriate gas flue leads to a stack, not shown.

The furnace **10** is provided with a plurality of vertically spaced rows of fuel burners **62, 64** and **66**, which are separately connected to a source of superatmospheric pressure preheated air for combustion and also connected to respective sources of fuel such as pulverizers C, B and A.

A regulable forced draft fan **94** is arranged to supply combustion air under pressure through duct **96** to air heater **80**, and serially connected ductwork components **102, 100, 98** conduct the heated air to the inlet **126** of windbox **104**, embracing the several rows of burners. Partitions **106, 108** and **110** (Fig. 2) divide a portion of the windbox into vertically spaced air chambers **112, 114, 116** and **118**, each of which is connected to the air inlet portion **128** of the windbox by its respective separately operable set of dampers such as **130, 129, 131** and **133**.

Each of the three burners in each horizontal row is connected by a separate primary air and pulverized fuel conduit to the same pulverizer. Conduits **134, 135** and **136** connect burners **62** to pulverizer C, conduits **146, 147** and **148** connect burners **64** to pulverizer B, while conduits **140, 141** and **142** connect burners **66** to pulverizer A. The coal pulverizers exemplify sources of a regulable supply of fluid fuel to be burned in suspension within the furnace and they are of the air swept type in which the rate of fuel delivery therefrom to the burners is regulated by changing the rate of flow of primary air flow through them.

A primary air fan **123** positioned intermediate the ends of the duct **124** is arranged to draw preheated air from chamber **118** and tempering air through dampered duct **152**, and discharge into the pulverizer A under control of volume regulating damper **150**. While a primary air fan has been shown and described with respect to pulverizer A only, corresponding separate primary air supply components are provided for pulverizers B and C, which receive preheated air from connections **122** and **120** respectively.

Provision for regulable gas recirculation similar in principle to that disclosed and claimed in my copending application Ser. No. 167,073 (now Patent 2,737,931 of March 13, 1956) is made as a component of the superheat temperature control of the illustrative unit. A fan **82** has its inlet connected by duct **84** to opening **86** in the gas flue **76** connecting the pass **52** to the gas inlet of the air heater. The outlet of the fan is connected by duct **88** including a regulating damper **400** to a plurality of nozzle or gas discharge ports **90** which are arranged in an elongated row and open through inter-tube spaces between the lower ends of hopper wall tubes to the space below the furnace hopper throat **92**.

The elevations of the three sets of burners are indicated by lines *a—a*, *b—b*, and *c—c* in Fig. 1. The uppermost row level *a—a* is spaced below the furnace gas outlet **12** to such an extent that under the maximum furnace temperature conditions to be experienced, the temperature of the gases leaving the furnace will not be in excess of a predetermined value based primarily on consideration of ash fusing temperatures. The lowermost row level, *c—c*, is at an elevation sufficiently above the hopper bottom to permit the desired cooling of ash particles separating from the products of combustion and dropping into the hopper in their passage to the ash pit below the throat **92**. The vertical spacing of the burner rows may be of a value of from 8 to 15 ft. in consideration of the above factors as well as the desired modification in furnace wall heat absorption.

When the unit is operating at maximum load or in the upper load range, when all three rows of burners are in operation and the combustible delivery substantially uniformly the same to all burners, the main combustion zone is in a zone opposite the burners, inasmuch as the burners are of the turbulent short flame type. The mean elevation of the main combustion zone can be considered to be represented by the line *b—b*.

On the other hand when the load on the unit is at such a lower value that two rows of burners will provide sufficient fuel, and only two rows of burners **62** and **64**, are operated, being supplied, for example, by pulverizers C and B, the main combustion zone will be at a higher elevation and the mean level of the main combustion zone will be at an elevation *d—d* intermediate lines *a—a* and *b—b*, inasmuch as burners **66** are inactive and the active main zone of combustion does not carry down into the furnace because the necessary overall gas flow is upward toward the furnace gas outlet **12**.

Fig. 5 is a graph illustrating the greater extent of superheat increase which may be accomplished by the concurrent utilization of gas recirculation and modification of the elevation of the combustion zone, as compared with what is attributable to the sum total of the individual effects of gas recirculation and modification of combustion zone elevation separately utilized. This graph is representative of the results which can be effected in an installation of the types shown by Figs. 1 and 6, having means for shifting the mean elevation of the combustion zone.

The lowermost curve M—M' indicates the variation of superheat temperature with operation of at least two vertically spaced rows of burners. The next curve N—N', extending somewhat parallel to curve M—M', represents superheat results attainable by shifting the elevation of the combustion zone by omitting the operation of the lowermost row of burners and carrying the load by the superposed burners. Thus at a load of 40%, the curve N—N' indicates a steam temperature of approximately 878° F., while curve M—M' at the same load is at 854° F. Shifting of the combustion zone thus gives an increase of 24 deg. at this load. If, however, the same rows of burners are operated as in the development of curve M—M', and a constant quantity of gas is recirculated to the bottom of the furnace, the superheat temperature will be in accordance with curve O—O', having a value of approximately 937° F. at 40% load. Gas recirculation will thus account for an increase in superheat from 854° F. to 937° F., or an increase of 83°. However, as the unit is operated after cutting out the lowermost row of burners as per N—N' but concurrently with the recirculation of the same amount of gas as in the development of curve O—O' the superheat at 40% load will be at 982° F., or an overall rise of 982 minus 854, or 128°, as indicated by curve R—P. Separately, the increase due to shifting the elevation as per N—N' amounts to 24°, while the effect of gas recirculation as per O—O' is 83° so that added together 24+83=107° of temperature rise is accounted for. However, the additional superheat rise (128° minus 107°=21°) is accomplished due to the concurrent gas recirculation and modification of elevation of the combustion zone, whereby the gas recirculation becomes more effective and a higher superheat temperature rise is accomplished with no greater expenditure of recirculating gas fan power or sacrifice in essential performance characteristics of the furnace.

The enhanced superheat control effect from concurrent gas recirculation and modification of the combustion zone position results from changes in heat transfer conditions in the furnace. Changes in average gas velocity and changes in the gas flow path length in the upper portion of the furnace alter the heat transfer exposure time period of gases flowing through the upper portion of the furnace. A modification of the combustion zone position away from a furnace wall subject to the covering effect of the recirculated gas as, for example, by raising the mean level of the combustion zone from *b—b* to *d—d*, is also a factor in enhancing the superheat control effect.

The effect is a function of change in the ratio of heat absorbing furnace wall area below the level of the main combustion zone, to the furnace heat absorbing area above the main combustion zone.

The control apparatus, depicted by Figs. 3 and 4, is arranged to facilitate the operation of the unit in accordance with the method of the invention. The left hand part of Fig. 3 of the drawings indicates a control system regulating the firing rate of the different rows of burners in accordance with indications of steam pressure and indications of boiler load. In the apparatus for this purpose, there is shown a steam pressure sensitive element **160** operatively associated with the pilot valve **162** by connections **164**. This pilot valve and the other pilot valves to be described below may be constructed in accordance with the description of the patent to Johnson 2,054,464. The pilot valve **162** controls the pressure loading in the line **166** connected to the relay **168**, preferably similar to the relay shown in the patent to Gorrie Re. 21,804. The modified loading from the relay **168** is transmitted through the line **170** and the boiler master selector valve **172** and line **174** to a pulverizer ratio controller **176**. Regulated control pressure loadings are transmitted from this ratio controller through the lines **192—196** to the selector valves **197—199** and the outgoing lines **200—202** to the operators **203—205** of the separate primary air dampers (such as **150**) of the separate pulverizers C, B, and A. The loading pressure in the line **174** is also transmitted to the averaging relay **210** by a line **178**. This relay is preferably constructed in accordance with the disclosure of the patent to Dickey 2,098,913, and the outgoing loading effected by this relay in the line **212** is a result of the combined effects of the loading in the line **178** and the loading in the line **214** extending from the relay **190** to the relay **210**. The line **214** transmits loadings effected by variations in boiler load as represented by steam flow and airflow variations which are respectively indicated by the steam flow meter **180** and the airflow meter **182**. The indications of these meters are regulably combined through the operative connections **184** and are controllably transmitted through the pilot valve **186** through the line **188** to the relay **190** and then to averaging relay **210**. The combined outgoing loading pressure from the relay **210** is transmitted to the line **212** and through the selector valves **216** and **218**. From the selector valve **216** a control loading line **220** transmits the ingoing loading to the calibrating relay **222** from which a modified outgoing loading is transmitted through the line **224** to the forced draft damper controller **226**.

From the relay **218** outgoing loading is transmitted by the line **228** to the differential relay **230** connected through a line **232** to the hydraulic tachometer **234** associated with the forced draft fan and by another line **236** transmitting loading to the relay **238**. This relay is preferably constructed in accordance with the disclosure of the patent to Fitch 2,441,405. The outgoing loading from this relay is transmitted through the line **240** to the forced draft fan valve operators **242** and **244** for the hydraulic coupling control valves **242'** and **244'**. Thus, the airflow for the combustion air is controlled from the steam pressure and the steam flow–airflow ratio impulses to control the damper position and forced draft fan speed. The furnace draft is controlled directly from the furnace draft controller **250** to sequentially control the speed of the induced draft fan and control its damper position by the apparatus indicated at the right hand part of Fig. 3. This includes a relay **252**, similar to relays **168** and **190**, having an incoming loading pressure transmitted thereto through the line **254** from pilot valve **256** which has operative connections **258** with the draft controller **250**. The outgoing loading from the relay **252** is transmitted through the lines **260—262** and then to the selector valves **264** and **266**. From the selector valve **264** outgoing loading pressure is transmitted through the line **268** as the incoming loading to the calibrating relay **270**. The outgoing loading pressure from this relay is transmitted through the line **272** to the induced draft fan outlet damper control drive **274**.

The regulated outgoing loading pressure from the selector valve **266** is transmitted through the line **276** to differential relay **278**, connected by the line **280** to the hydraulic tachometer **282** associated with induced draft fan. Also leading from the relay **278** is a line **284** transmitting loading to the relay **286**. The modified and regulated outgoing loading from this relay is transmitted through the line **288** to the operators **290** and **292** associated with hydraulic coupling valves **294** and **296**, the hydraulic coupling being utilized for speed variation of the induced draft fan.

In conjunction with the described control system, the induced draft fan may be considered as disposed in a conventional position in the gas flow paths of each of the Fig. 1 and Fig. 6 units, and the Fig. 6 unit may be considered as having a forced draft fan and pertinent associated structures similar to those shown for the forced draft fan #94 of the Fig. 1 unit. Each fan, according to the pertinent control system, is subject to both speed control, and flow control through damper regulation. The speed of each fan is regulated by fluid flow through hydraulic coupling valves such as **242'** and **244'** in the fan drive. Since the fan speed changes will not only change the volume of gas or air delivered, but also the gas or air pressure, the extent of air or gas flow regulation by fan speed alone is limited. Any increase or decrease in fan air or gas flow, beyond that obtainable by changes in fan speed, is obtained by damper regulation, as by the regulations of vanes in the fan inlet, as positioned by the power piston or damper operator **226** or **274**, the latter becoming operative below the selected fan speed operating range.

In the above described control system, the selector valves such as **197**, **216**, and **266** are preferably constructed in accordance with the disclosure of the patent to Fitch 2,202,485, May 28, 1940 and the interconnected steam flow and airflow meters **180** and **182** are constructed and arranged somewhat in accordance with the patent to Albright 1,962,676, June 12, 1934. The differential and averaging relays involved in this control system are preferably constructed in accord with the disclosure of the patent to Dickey 2,098,913, November 9, 1937.

For boiler loads for which the final steam temperature would be lower than optimum, the temperature will be raised by recirculating flue gases. The controls for flue gas recirculation are indicated in Fig. 4. In this system the three controlling impulses are boiler load, as indicated by the boiler meter **300**, final steam temperature, as indicated by the temperature controller **302**, and recirculated gas flow as indicated by the flow meter **304**. These components are also recorder-controllers. For flue gas recirculation, the boiler load impulse from the meter **300** calls for a decreasing amount of recirculated gases as boiler load increases. This change in flow of recirculated gas is effected through adjustment of the damper **306** in the duct **84** leading to the recirculating gas fan **82**. The flow meter **304** is effective upon the damper through the pilot valve **308**, the line **310**, the relay **312**, the line **314**, selector valve **316** and the damper operator **318**. The temperature controller **302** delivers control impulses (representative of changes in superheat, or final steam temperature) which are effective upon the recirculated gas damper **306** through the pilot valve **320**, the line **322**, the relay **324**, line **326**, line **328**, the relay **330**, the line **332**, relay **312**, and the previously described connections to the damper. Boiler load impulses as initiated by the boiler meter **300** are effective through the pilot valve **334** and the line **336** leading to the relay **330**. At this relay, the effect of the boiler load impulses is modified by the effect of the steam temperature impulses arriving at the relay **330** through the line **328**, the modified result being effective through the line **332**, the relay **312** and its previously described connections with the damper **306**.

The control system represented by Fig. 4 provides automatic starting and stopping the recirculation fan **82** by means of a ratio controller **340**. This controller operates from a loading pressure for the spray attemperator control valve **342**, this loading pressure being effective through the line **344** which leads from the loading line **346** leading to the operator **348** for the attemperator control valve. The other loading pressure operative upon the ratio controller **340** is effective through the line **350** leading from the line **314** to the operator **318** of the recirculated gas damper **306**. The contact points **352** and **354** of the ratio controller are set so as to close the circuit for the recirculated gas fan motor **356** as the loading pressure on the spray attemperator drops to a certain point, say 4 lbs., and when the loading pressure to the recirculation damper drive **318** rises to a certain point, say 3 lbs., to start the recirculation fan motor. As the boiler load increases, the loading pressure in the line **314** to the recirculation damper drive **318** decreases while the spray attemperation loading in the line **346** increases, thus providing a very positive closing point for the circuit for the motor **356**. This controller may be adjusted so as to start the motor **356** at any desired relation between the two loading pressures, thus making it possible to start the fan motor while the attemperator is in operation, or to provide a gap between the period of operation of the attemperator and the start of the recirculation fan.

For higher boiler loads, where steam temperature would otherwise exceed the final steam temperature desired, the temperature of the steam is reduced by spray water into the attemperator **42** in such controlled quantity as to provide the proper final steam temperature. To control the amount of spray water required for maintaining the desired temperature for the higher loads, the attemperator control valve **342** is operated from the controlling impulses representing, respectively, boiler load from the meter **300**, final steam temperature from the temperature controller **302**, and attemperator outlet temperature. The impulses representing attemperator outlet temperature are effective through the temperature controller **302**, the pilot valve **360**, and the line **362** leading to the relay **364**. The impulses representing final steam temperature are effective upon the relay **364** to modify the relay effect of the impulses from attemperator outlet temperature, through the pilot valve **320**, the line **322**, the relay **324** and the line **326**, the relay **366** and the line **368**. In the relay **366** the impulses represented by boiler load are effective to modify the impulses represented by final steam temperature, through the boiler meter **300**, the pilot valve **370** and the line **372**.

The control system indicated in Fig. 4 will also involve an electrical interlock operating from the recirculation fan motor circuit so as to hold the recirculation damper drive **318** in the closed position unless the fan motor is running. In addition to this interlock, the system will involve an extra set of shut off dampers in the recirculation duct, in addition to the control damper **306**. There will be a vent **406** connected with the duct **88**, and a damper **402** in the outlet of the vent. Between the vent and the nozzles **90** there will be a damper **400** so associated with the controlling mechanism that when the fan **82** is inoperative the damper **402** and the vent **406** will be open and the damper **400** open. At this time the damper **306** is closed. The provision of the open vent under these conditions prevents the flow of hot combustion gases from the furnace directly to the inlet **86** of the gas recirculating system.

With the described arrangement of boiler unit, regulable fuel supply means and control apparatus, the vapor generator unit may be operated through a wide load range with the attainment of a substantially constant degree of steam temperature. The method of operation will be according to the procedure hereinafter described.

With the unit in operation at a load of or near to 100% of capacity, fuel will be delivered to the three rows of burners from their respective pulverizers A, B and C. The regulation of the rate of fuel burning will be controlled by the automatic manipulation of the primary air supply to the individual pulverizers from vapor pressure indications as a steam demand index.

When the vapor demand falls and the vapor pressure tends to increase, the fuel supplied to the burners will be automatically decreased. As the load is progressively decreased the heat absorbed by the superheater will decrease and when the load is decreased below the control point corresponding to 1000° F. final steam temperature and about 79% load, as indicated by Fig. 5, the delivered vapor temperature would be below optimum except for the modification of operation which will be automatically initiated by the control apparatus.

When the load decreases from the control point, the steam temperature controller **302** will initiate the operation of the recirculating fan and cause the introduction of recirculated gas to bring about a modification of furnace wall heat absorption to an extent leaving sufficient heat in the gases passing over the superheater so that the optimum temperature will be attained.

With still further reduction in steam demand or load the automatic combustion control will reduce fuel delivery and the amount of gas recirculated will be automatically increased in accordance with steam temperature requirements. At some intermediate load, the value of which may be observed by the operator from boiler load controller **300**, the rate of gas recirculation will have increased to a predetermined maximum value which will be indicated by flow meter and controller **304**. With these indications, the operator will modify the operation upon a further reduction of load, by manipulating selector valve **199** to cause controller **205** associated with damper **150** in the primary air supply duct of pulverizer A, to be taken out of control. Controller **205** will then automatically close damper **150** and the fuel delivery from pulverizer A to the lower row of burners **66** will cease.

With elimination of the supply from pulverizer A, the delivery of fuel from the remaining pulverizers B and C will be corespondingly increased in order to maintain the steam pressure. However, as the mean level of the main combustion zone will be raised from a level approximating line *b—b* (when all burners are in operation) to one approximating line *d—d* as indicated in Fig. 1, the augmented superheat modifying effect previously described would give a vapor temperature in excess of optimum if the amount of gas recirculation used with the prior three pulverizer and three burner level operation were continued. The line *d—d* is intended to indicate the mean level of the main combustion zone with only the top two rows of burners in operation. The line has similar significance with only the topmost row of burners in operation, and the lines *b—b* and *c—c* similarly apply to their associated rows of burners.

The vapor temperature controller **302** will sense this tendency for the vapor temperature to increase and through its control connections will automatically reduce the quantity of the recirculated gas to bring the vapor temperature to the optimum value.

When the load is increased to a value where it is considered desirable to operate three pulverizers and the three corresponding rows of burners, the operator will start the idle pulverizer such as A, and then when it is at operative speed and delivering fuel subject to manual control, make it subject to regulation by the automatic control system through manipulation of selector **199** whereby the control pressure of line **196** is transmitted to line **202**.

In Fig. 6 of the drawings the invention is illustrated as embodied in a steam generating and superheating unit having a vertically elongated furnace chamber **500** of rectangular cross section, the front and rear walls **502** and **504** of which are delineated by upright steam generating tubes **506** and **508** respectively. The opposite side walls have similar wall tubes directly connecting top and bottom headers **510** and **512** respectively. The portions of the front and side wall tubes at the burner level are of refractory covered stud construction. All of the wall tubes are connected into the circulation system which includes an upper steam and water drum **514** and a lower water drum **516**, connected by banks **518** and **520** of steam generating tubes. The tubes **506** and **508** discharge into the drum **514** and have headers **522** and **524** respectively at their lower ends, connected in a well known manner to the drum. In the path of the gases flowing from the furnace are groups of bent screen tubes **526** forming continuations of the rear wall tubes **508**. A convection heated pendant type superheater, formed by two banks of tubes **528** and **530**, is positioned in the gas flow path between the screen tubes and the vapor generating bank **518**, the screen tubes being arranged to screen the superheater tubes from furnace radiation. In this instance the superheater tubes receive heat from the gases by radiant and convection transmission from the stream of heating gases, but the convection transmission is predominant because of the small lateral spacing of the tubes and the relative temperature of the gases. If the superheater were located in a higher gas temperature zone and with a greater lateral spacing, the proportion of heat transmitted by radiation as compared with convection transmission would be increased. The steam flows from the steam space of the drum **514** through tubes **532** to the bank of tubes **530** and intermediate header **533** and thence through the bank of tubes **528** to the superheater outlet header **534**.

The furnace chamber **500** is fired by two rows of horizontally arranged burners **536** and **538** disposed at different levels, and directing burning fuel and air in mixing relationship through corresponding burner ports **537** and **539** respectively in the front wall **502** into the furnace chamber. The burners are shown as fired by pulverized fuel delivered from pulverizers **535** in suspension in primary combustion air through burner supply pipes **540** and **542** respectively. The pulverizers are preferably equipped with valve mechanisms such as those shown at **60—63** in Fig. 2 of the patent to Schwartz 2,275,595, March 10, 1942, for shutting off the fuel flow in selected fuel conduits leading to the burners. Heated secondary combustion air is supplied under a positive pressure from a windbox **544** enclosing the burner ports **537**, **539**.

The furnace illustrated is of the water cooled hopper bottom type with the rear furnace wall **504** and the rear sloping hopper wall **548** having the tubes **508** arranged in a tube-to-tube construction. Between the rear wall **548** and the sloping front wall **552** of the hopper **550**, there is a throat opening **554** through which the incombustible solid residues of combustion pass into a closed ash pit **557** having opposite walls **556** and **558**.

The pulverized fuel burners **536** and **538** are high capacity burners of the short flame turbulent type preferably having secondary control means such as the vanes **44** shown by the patent to Poole 2,380,463, July 31, 1945, for shutting off the flow of secondary air when a burner is taken out of operation. The burners are arranged to discharge pulverized fuel and combustion air in intimate mixing relationship into the furnace through the corresponding front wall burner ports. The mixtures of fuel and air are ignited immediately on entering the furnace and the burning fuel and air mixtures move toward the rear wall of the furnace at a substantial velocity, but the front to back dimension of the furnace is so designed that, even at maximum high velocity introduction of fuel and air, the combustion products will not impinge to any substantial extent upon the rear furnace wall **504**.

While the burning fuel and air mixtures expand greatly on ignition, their velocity of introduction is not quickly dissipated so that the center section of the furnace, i. e. the main combustion zone, may be considered to be filled with an expanding stream of burning fuel, air and products of combustion at a substantial velocity which, under the influence of the furnace draft, turns upwardly towards the furnace gas exit **545** at the level of the water drum **516**.

With the walls of the furnace defined by rows of steam generating tubes absorbing heat radiantly transmitted thereto from the burning fuel and heating gases generated, it is necessary to position the burners **536** and **538** at elevations sufficiently below the furnace gas exit **545** so that the gases will be cooled to such a degree that slagging of the screen tubes **526** and superheater tubes **528** and **530** will not result.

The burners are also positioned a sufficient distance above the water cooled hopper bottom **550** so that molten ash particles separating from the burning fuel stream and dropping to the bottom will pass through a lower temperature gas zone below the active combustion zone intermediate the height of the furnace, and be chilled to a solidifying temperature for removal in a dry condition. While the main stream of high temperature gaseous products of combustion is developed above this lower furnace zone, the gas stream does not flow directly through it, the hopper space being filled with lower velocity gas eddy currents. The hopper gases however do transmit considerable heat which is absorbed by the steam generating tubes lining the hopper walls and the vertical walls below the level of the combustion zone.

The heating gas stream leaving the furnace outlet **545** flows across the screen tubes **526** and superheater tube banks and through the baffled boiler tube banks **518** and **520**. The gases leave the boiler bank **520** at the upper portion thereof and the major portion of the gases pass, as indicated by arrows **562** and **564**, to a regenerative type air heater **560** from which they pass to draft inducing apparatus, such as an induced draft fan and/or stack (not shown), for discharge to the atmosphere. The induced draft fan connections would involve gas flow control vanes or dampers as indicated in the preceding description of the control system.

A gas recirculation system, operable in accordance with the invention to return a portion of the inert gases leaving the boiler bank **520**, is provided by a vertical gas duct **563**, recirculating fan **566**, and serially connected discharge ducts **568**, **569** and **570**, the duct **570** extending along and substantially throughout one side of the hopper throat **554** and having discharge flow passages between the spaced lower ends **574** and **576** of the tubes **508** into the throat **554**. Duct **568** contains an automatically operable control and shut-off damper **590**. Duct **568** is also provided with a port **584** in one side thereof between the damper **590** and furnace end. A resiliently loaded damper **586** of any suitable type is positioned in this port as an automatic atmospheric communication means.

In accordance with the present invention, the tendency of the convection superheater to effect a decrease in superheat temperatures with decreases in load is, at least, partially offset by variable operation of the inert gas recirculation provisions described. At fractional loads either row of fuel burners may be used, although for the lowest operating loads operation of the upper row of burners **536** alone is preferred from the standpoint of superheat control. When the burners of each separate row are fired by fuel from a separate pulverizer, the burners of one row may be rendered inoperative by shutting down the pertinent pulverizer.

With the lower row fuel burners **538** alone in operation and the boiler delivering heating gases to the air heater (and with the mean level of the main combustion zone at approximately the level *b'—b'*), the recirculating fan **566** may be operated to withdraw a portion of the gases from the boiler gas outlet, as indicated by the arrow **565**, and discharge them through the discharge ducts **568**, **569**, **570** when the damper **590** is in an open position. The recirculated inert gases are delivered by the fan to the furnace hopper throat, entering the throat with only sufficient velocity to insure uniform distribution along the length thereof. The low velocity recirculated gases move upwardly in the hopper and suppress the tendency of eddy currents of freshly developed high temperature combustion gases to circulate within the hopper zone. The continuous introduction of the cooler inert gases modifies the character of the flow path of the stream of high temperature products of combustion generated by the newly burned fuel, as the gas stream flows towards the furnace gas outlet.

The illustrated steam boiler installation has a maximum steam delivery rate of 160,000 lb. of steam per hour at a superheat temperature of the order of 900° F. and a pressure of 660 p. s. i. Tests carried out in the operation of this installation have indicated that at a steam delivery rate of 80,000 lb. of steam per hr., i. e. 50% of full load, the superheated steam temperature with only the lower row of burners **538** in service and in the customary manner without gas recirculation is only 750° F. Tests have shown that by gas recirculation in accordance with the invention, the superheat steam temperature can be raised to 900° F. by use of a recirculation rate of approximately 28% of the weight of the gases developed by the combustion of the fuel, when the lower burners alone are in service and at the same operating load.

When the three upper burners **536** only were used, for a corresponding operating load, the superheated steam temperature without gas recirculation was 810° F. It was found that a lower rate of gas recirculation than that necessary with the lower row of burners alone would readily raise the superheated steam temperature to 900° F.

The lines *a'—a'*, *b'—b'* and *c'—c'*, indicate the approximate levels of the main combustion zone under three conditions; viz: when only the upper burners are in operation; when only the lower burners are in operation; and when all burners are in operation.

Operation of the described unit with and without gas recirculation at low operating loads has proven that the method of the invention is effective in attaining the desired superheat temperature at a very low steam delivery rate, with either row of burners in operation. Under even these low load conditions the flame is stable and flame temperature determinations by customary measurement methods show no significant change in flame temperatures due to the use of recirculated gases.

The resiliently loaded damper **586** arranged in port **584** in the side wall of the duct **568** at a position between the damper **590** and the furnace discharge openings from the discharge duct **570** is advantageous in maintaining satisfactory conditions within the gas recirculating system when it is not in use, as for example, at high load rates of operation when the desired superheat temperature is attainable without gas recirculation. Under such conditions when fan **566** is not operated and damper **590** is in a closed position for the purpose of avoiding any reverse flow of gases through ducts **570**, **569**, **568**, and **563**, the absolute pressure on the fan side of damper **590** will correspond to that at the position where duct **563** is connected to the gas outlet from boiler bank **520**. The resiliently loaded damper **586** is constructed so that when the pressure in the duct is above a predetermined pressure relative to the pressure in the throat of the furnace hopper, it will be held in a closed position. When the pressure at the damper **586** corresponds to or is below that of the predetermined pressure, atmospheric pressure will overcome the damper loading, opening the damper so that atmospheric air will be drawn through the port **584** into duct **568**. This automatic introduction of relatively low temperature atmospheric air will cause a flow of cool air rather than gases from the furnace throat back through duct **568**, fan **566**, and duct **563** in case the damper **590** should not be gas tight in its closed position.

Variation in the rate of delivery of recirculated gases is accomplished by adjustment of the position of damper **590**. This may be done manually by the operator in accordance with indications of superheated steam outlet temperature. However, a damper operating device can be adapted for connection to automatic steam temperature measurement apparatus (not shown), so that the rate of gas recirculation may automatically be regulated in accordance with steam superheat temperature. As the superheat temperature tends to fall with decrease in load, the damper would thus be automatically adjusted to permit more gas to be recirculated, and vice versa.

While the increase of steam superheat temperature by means of gas recirculation to the furnace is of great value for superheat temperature control in connection with the normal operating load range of the boiler unit, the invention is also of particular advantage in starting up boiler units where it is desired to fire the unit and deliver a relatively low rate of steam at a predetermined minimum temperature. Inasmuch as the introduction of recirculated gases in the manner of the invention does not affect burner operation, it is possible to use the method disclosed at a very low delivery rate from the unit. A low steam delivery rate is all that is usually required to turn over and gradually bring up to speed the prime mover served by the boiler. When a non-operating prime mover, as, for example, a steam turbine, has been retained at high temperature, it is undesirable to introduce steam of low superheat to bring the turbine up to speed. The use of the invention permits the delivery of steam at a relatively high temperature even though the delivery rate may be as low as 5 to 20% of the full load steam delivery rate of the unit.

The area of the gas introduction ports as determined by their length and the width of the intertube spaces is such that the gas delivered through the ports enters the furnace at relatively low velocity in non-mixing relationship as regards relative velocities with the gases developed by direct fuel combustion. The recirculated gases so introduced will spread through the hopper, maintaining strata of relatively cool gases between the main combustion zone and the hopper walls, while the gases from the hopper zone as heated up will pass upward and through the furnace.

While the invention has been illustrated as used with pulverized fuel burners, it is also adapted for use with other fluid fuel burners, such as oil or gas burners.

The disclosed introduction of a stream or streams of low temperature inert recirculated gas into the furnace in a manner so as to avoid mixing of the streams with either the secondary combustion air or with the mixture of fuel and air delivered through the burner ports, is particularly important from the standpoint of efficient and stable burner performance. Dilution of the combustion air with inert recirculated gases and thereby retardation of combustion and lengthening of the flame is avoided. Retardation of combustion and lengthening of flame in a furnace normally result in a lower combustion efficiency due to a higher unconsumed carbon loss, particularly in the fly ash.

It is within the purview of the invention that the modified unit shown in Fig. 6 is subject to a control system similar to the previously described system, including the control components shown in Figs. 1, 3, and 4.

While in accordance with the provisions of the statutes I have illustrated and described herein the best form of my invention now known to me, those skilled in the art will understand that the 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 my invention may sometimes be used to advantage without a corresponding use of other features.

I claim:

1. The method of maintaining a predetermined temperature of superheated steam delivered from a steam generator having a vertically elongated furnace with tubular water flow elements in the lateral walls and throughout the major extent of its height for receiving heat and generating steam, convection steam superheating elements located beyond the furnace gas outlet from the upper end of the furnace and in the path of heating gases flowing therefrom and fuel burning means arranged and constructed to deliver fluid fuel and combustion air to a combustion zone at different levels intermediate the height of the furnace, the method comprising the steps of; burning the preponderant portion of fuel in suspension in a combustion zone having a mean elevation intermediate the height of the furnace to produce high temperature heating gases, imparting heat from the gases to water as the gases flow upwardly in an elongated flow path to generate steam to meet a high load steam demand and to partially cool the gases, passing the gases in a flow path in heat transfer relationship with steam superheating elements to superheat steam and to further cool the gases, variably introducing a recirculated portion of the partially cooled gases from a position in the gas flow path downstream of the steam superheating heat transfer zone to a position within the furnace substantially below the mean elevation of said combustion zone to reduce heat transfer to the water surrounding the furnace zone subjacent the combustion zone, increasing the rate of said recirculated gas introduction as load decreases, and as the steam demand is decreased decreasing the fuel burning rate in a combustion zone the mean elevation of which is lower than the mean elevation of the combustion zone of the higher load and less remote from the point of recirculated gas introduction, whereby the vertical extent of the furnace zone subjacent the combustion zone is increased to effect a reduction in heat transfer to the surrounding water tubes and whereby the superheat regulation effect of the gas recirculation is enhanced.

2. The method of maintaining a predetermined superheated vapor temperature in a vapor generator having a furnace with its boundaries substantially defined by tubular heat absorbing elements and having a convection superheater located beyond the furnace outlet and heated by gases therefrom, the method comprising; the burning of fuel in suspension at a first furnace position remote from said outlet in a gas flow sense and imparting heat from the gases produced thereby to portions of said heat absorbing elements located in an adjacent portion of the furnace; simultaneously burning fuel in suspension at a second furnace position less remote from said outlet than said first position; imparting heat from the gases produced at the first position and from the gases produced by fuel burning at the second position to the portions of the heat absorbing elements located adjacent the second position; passing the combined gases from the furnace over the superheater; and controlling superheat under changing load by varying the heat absorbed by said elements by concurrently controllably varying the amount of fuel burned at the first position and variably introducing into the furnace cooled gases from a position gas flow-wise downstream of said furnace outlet, the varying of the fuel burning at said first position involving a decrease in the fuel burning rate as vapor demand is decreased and the variable introduction of cooled gases involving an increase in said introduction as the vapor demand decreases.

3. In a vapor generating and superheating installation, a vapor generating section including a furnace with vapor generating tubes generally defining the furnace combustion chamber, a superheater heated by the gases from the furnace, separately controllable first and second fuel burning means firing the furnace at different furnace positions successively more remote from the furnace gas outlet in a gas flow sense, and superheat control means including a gas recirculation system ductwork having a gas inlet communicating with furnace gas flow beyond said outlet, said ductwork having an outlet communicating with the furnace; said superheat control means including first means regulating the amount of gas recirculated by said system in accord with indications of superheat temperature and rate of vapor generation, the first regulating means increasing the recirculated gas flow when the indications of superheat temperature and vapor generation rate decrease in value, said superheat control means also including second regulating means effective from vapor pressure indications and indications representative of rate of vapor generation to vary the rate of firing of the second fuel firing means to maintain superheated vapor temperature at a predetermined value at low rates of vapor generation, said second regulating means increasing the firing rate of the second fuel firing means when the vapor pressure decreases and when the rate of vapor generation is to be increased.

4. In a vapor generating and superheating installation, a vapor generating section including upright vapor generating tubes generally defining a furnace combustion chamber in which vapor generation results mainly from the radiant transmission of heat from combustion elements to the tubes and the vaporizable fluid therein, means forming a combustion chamber gas outlet and a convection gas pass leading therefrom, a convection section including a convection superheater in the gas pass, fuel burning means adapted to effect the mean level of the main combustion zone at different vertically spaced positions under different loads, a gas recirculation system introducing combustion gases from a position beyond the combustion gas entrance to the superheater to a position in the combustion chamber below the fuel burning means, means increasing the flow of recirculated gases when the mean level of the main combustion zone rises, and means controlling the firing means to decrease the total firing rate and elevate the mean level of the main combustion toward its highest level as the vapor demand decreases, the flow of recirculated gases increasing as the rate of vapor generation decreases.

5. The method of maintaining a predetermined temperature of superheated steam delivered from a steam generator having a vertically elongated furnace with tubular water flow elements in its lateral walls and

throughout the major extent of its height for receiving heat and generating steam, convection steam superheating elements located beyond the furnace gas outlet from the upper end of the furnace and in the path of heating gases flowing therefrom, and fuel burning means arranged and constructed to deliver fluid fuel and combustion air to a combustion zone at different levels intermediate the height of the furnace; the method comprising the steps of; burning the preponderant portion of fuel in suspension in a combustion zone having a mean elevation intermediate the height of the furnace to produce high temperature heating gases, imparting heat predominantly by radiation from the gases to water as the gases flow upwardly in an elongated flow path to generate steam to meet a high load steam demand and to partially cool the gases, passing the gases in a flow path in convection heat transfer relationship with steam superheating elements to superheat steam and thereby further cooling the gases, variably introducing a recirculated portion of the partially cooled gases from a position in the gas flow path downstream of the steam superheating heat transfer zone to a position within the furnace substantially below said combustion zone to reduce the radiant heat transfer to the confined water streams surrounding the furnace zone subjacent the combustion zone, increasing the rate of said recirculated gas introduction and thereby decreasing radiant heat transfer for steam generation and increasing the convection superheating effect by increased gas mass flow as load decreases, and, simultaneously, as the steam demand is decreased, decreasing the fuel burning rate in a combustion zone the mean elevation of which is lower than the mean elevation of the combustion zone of the higher load and less remote from the point of recirculated gas introduction, whereby the vertical extent and volume of the furnace zone subjacent the combustion zone is increased to effect a reduction in radiant heat transfer to the surrounding water tubes and whereby the superheat regulation effect of the gas recirculation is enhanced.

6. The method of maintaining a predetermined superheated vapor temperature in a vapor generator having a furnace with its boundaries substantially defined by tubular heat absorbing vapor generating elements conducting confined streams of a vaporizable liquid, the vapor generator also having a convection vapor superheater located beyond the furnace outlet and convectionally heated by gases therefrom, the method comprising: the burning of fuel in suspension in a first furnace zone remote from said outlet in a gas flow sense and imparting heat predominantly by radiation from the combustion gases to portions of said confined streams located in an adjacent portion of the furnace; simultaneously burning fuel in suspension in a second furnace zone less remote from said outlet than said first zone; imparting heat from the combustion gases produced in the first zone and from the gases produced by fuel burning in the second zone to the portions of the confined streams located adjacent the second zone; convectionally superheating the generated vapor by passing the combined gases from the furnace through the superheating zone, and controlling superheat under changing load by varying the heat absorbed by said confined streams by concurrently controllably varying the amount of fuel burned in the first zone and variably introducing into the furnace cooled gases withdrawn from a position gas flow-wise downstream of the superheating zone, the varying of the fuel burned in said first zone involving a decrease in the fuel burning rate as vapor demand is decreased and the variable introduction of cooled gases involving an increase in said introduction as the vapor demand decreases.

7. The method of maintaining a predetermined superheated vapor temperature in a vapor generator having a furnace with its boundaries substantially defined by tubular heat absorbing vapor generating elements conducting confined streams of a vaporizable liquid, the vapor generator also having a convection superheater located beyond the furnace outlet and heated by gases therefrom, the method comprising: the burning of fuel in suspension in a first furnace zone remote from said outlet in a gas flow sense and imparting heat predominantly by radiation from the combustion gases to portions of said confined streams located in an adjacent portion of the furnace; simultaneously burning fuel in suspension in a second furnace zone less remote from said outlet than said first zone; imparting heat from the gases produced in the first zone and from the gases produced by fuel burning in the second zone to the portions of the confined streams located adjacent the second zone; convectionally superheating the generated vapor by passing the combined gases from the furnace through the superheating zone; and controlling superheat under changing load by varying the heat absorbed by said confined streams by concurrently controllably reversely varying the amount of fuel burned in the first zone and variably introducing into the furnace cooled gases withdrawn from a position gas flow-wise downstream of the superheating zone; the introduction of the cooled gases into the furnace being effected at a position more remote from the superheating zone than at least one of the zones of fuel burning; the varying of the fuel burned in said first zone involving a decrease in the fuel burning rate as vapor demand is decreased and the variable introduction of cooled gases involving an increase in said introduction as the vapor demand decreases.

8. The method of maintaining a predetermined superheated vapor temperature in a vapor generator having a furnace with its boundaries substantially defined by tubular heat absorbing vapor generating elements conducting confined streams of a vaporizable liquid, the vapor generator also having a convection superheater located beyond the furnace outlet and heated by gases therefrom, the method comprising: the burning of fuel in suspension in a first furnace zone remote from said outlet in a gas flow sense and imparting heat predominantly by radiation from the combustion gases to portions of said confined streams located in an adjacent portion of the furnace; simultaneously burning fuel in suspension in a second furnace zone less remote from said outlet than said first zone; imparting heat from the gases produced in the first zone and from the gases produced by fuel burning in the second zone to the portions of the confined streams located adjacent the second zone; convectionally superheating the generated vapor by passing the combined gases from the furnace through the superheating zone; and controlling superheat under changing load by varying the heat absorbed by said confined streams by concurrently controllably reversely varying the amount of fuel burned in the first zone and variably introducing into the furnace cooled gases withdrawn from a position gas flow-wise downstream of the superheating zone; the introduction of the cooled gases into the furnace being effected at a position more remote from the superheating zone than the zones of fuel burning; the varying of the fuel burned in said first zone involving a decrease in the fuel burning rate as vapor demand is decreased and the variable introduction of cooled gases involving an increase in said introduction as the vapor demand decreases.

9. In a vapor generating and superheating installation, a vapor generating section including upright vapor generating tubes generally defining a furnace combustion chamber in which vapor generation results mainly from the radiant transmission of heat from combustion elements to the tubes and the vaporizable fluid therein, means forming a combustion chamber gas outlet and a convection gas pass leading therefrom, a convection section including a convection superheater in the gas pass, fuel burning means adapted to effect the mean level of the main combustion zone at different positions, a gas recirculation system including a fan and ductwork introducing combustion gases from a position beyond the

combustion gas entrance to the superheater to a position in the combustion chamber below the fuel burning means and more remote from the combustion chamber gas outlet, means increasing the flow of recirculated gases as the rate of vapor generation decreases and under a firing condition involving the increasing of the mean level of the main combustion zone above its lowermost operative level, and means controlling the firing means to decrease the total firing rate and elevate the mean level of the main combustion toward its highest level as the vapor demand decreases.

10. In a vapor generating and superheating installation, a vapor generating section including upright vapor generating tubes generally defining a vertically elongated furnace combustion chamber in which vapor generation results mainly from the radiant transmission of heat from combustion elements to the tubes and the vaporizable fluid therein, means forming a combustion chamber gas outlet and a convection gas pass leading therefrom, the outlet being disposed at the upper portion of the combustion chamber, a convection section including a convection superheater in the gas pass, fuel burning means adapted to effect the mean level of the main combustion zone at different positions, a gas recirculation system including a fan and ductwork introducing combustion gases from a position beyond the combustion gas entrance to the superheater to a position in the combustion chamber below the fuel burning means and more remote from the combustion chamber gas outlet, means increasing the flow of recirculated gases as the rate of vapor generation decreases and under a firing condition involving the increasing of the mean level of the main combustion zone above its lowermost operative level, and means controlling the firing means to decrease the total firing rate and elevate the mean level of the main combustion toward its highest level as the vapor demand decreases.

11. In a vapor generating and superheating installation, a vapor generating section including upright vapor generating tubes generally defining a vertically elongated furnace combustion chamber in which vapor generation results mainly from the radiant transmission of heat from the combustion elements to the tubes and the vaporizable fluid therein, means forming a combustion chamber gas outlet and a convection gas pass leading therefrom, the outlet being disposed at the upper portion of the combustion chamber, a convection section including a convection superheater in the gas pass, fuel burning means including upper and lower rows of burners adapted to effect the mean level of the main combustion zone at different positions, a gas recirculation system including a fan and ductwork introducing combustion gases from a position beyond the combustion gas entrance to the superheater to a position in the combustion chamber below the fuel burning means and more remote from the combustion chamber gas outlet, superheat control means responsive to operative variables including changes in superheated vapor temperature for increasing the flow of recirculated gases as the rate of vapor generation decreases and under a firing condition involving the increasing of the mean level of the main combustion zone above its lowermost operative level, said superheat control means regulating the firing means to decrease the total firing rate and elevate the mean level of the main combustion toward its highest level as the vapor demand decreases; and means for attemperating the superheated vapor at rates of vapor generation beyond the upper limits of superheat control by the combination of the recirculated gas introduction and the concurrent variation in level of the main combustion zone.

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