May 8, 1962 P. H. KOCH 3,033,178

VAPOR GENERATING AND SUPERHEATING UNIT WITH RECIRCULATED GAS INTRODUCTION ALONG FURNACE FLOOR

Filed Sept. 25, 1953 2 Sheets-Sheet 1

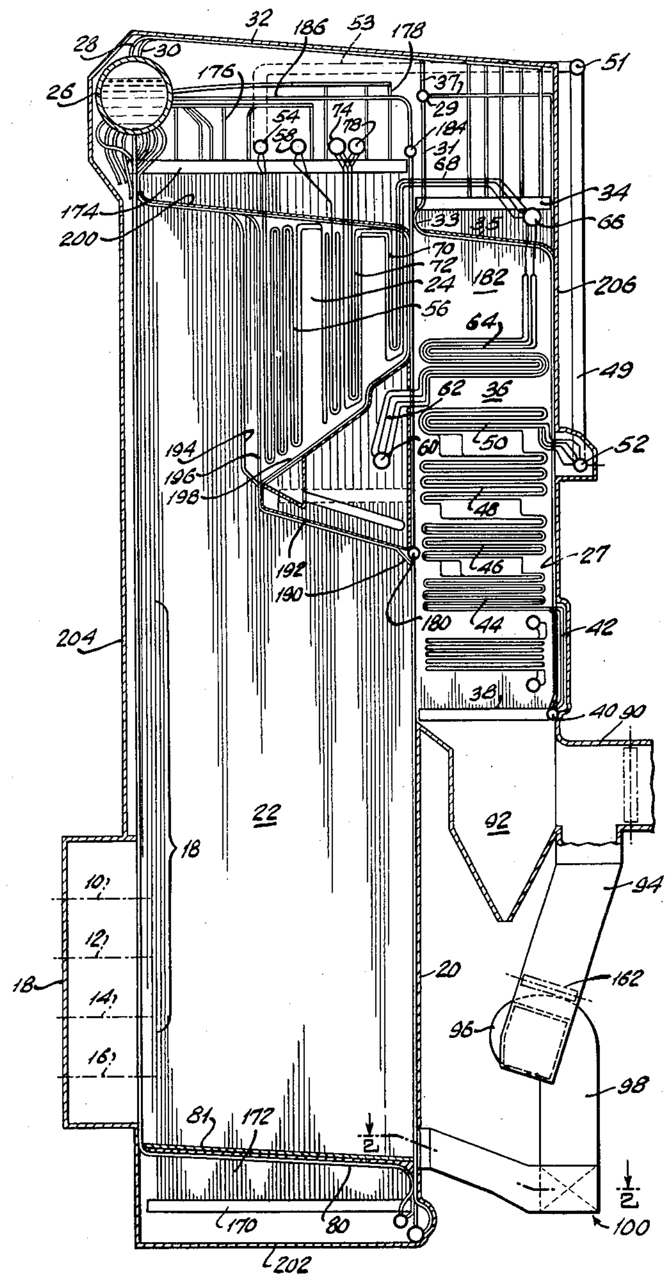

Fig. 1.

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Fig. 2.

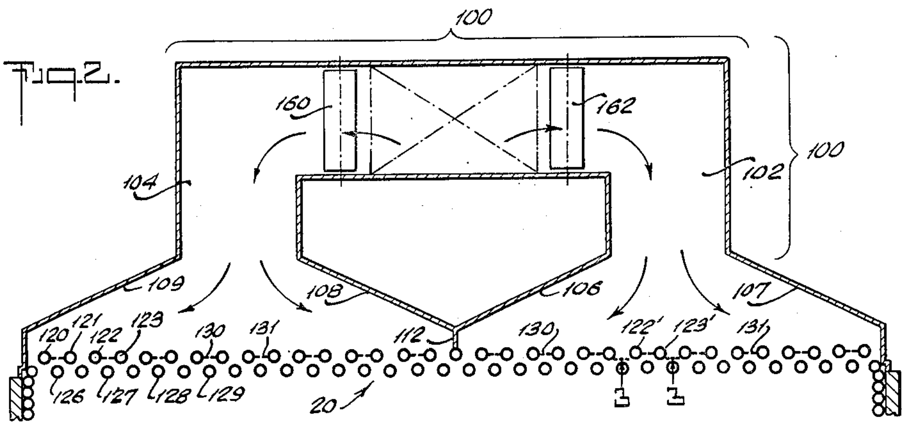


Fig. 3.

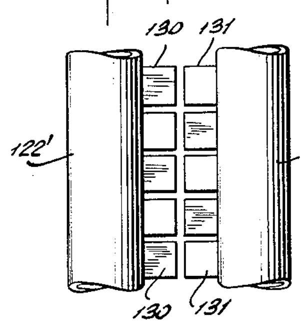


Fig. 4.

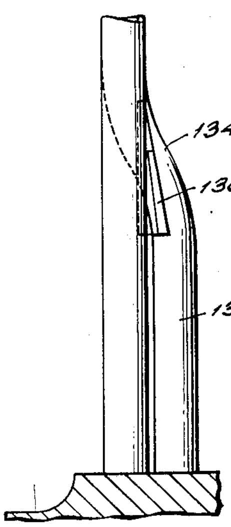
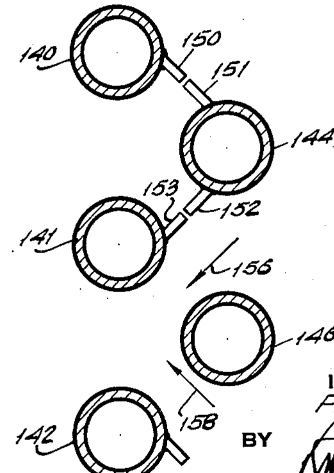


Fig. 5.



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VAPOR GENERATING AND SUPERHEATING UNIT WITH RECIRCULATED GAS INTRODUCTION ALONG FURNACE FLOOR

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3 Claims. (Cl. 122—478)

This invention relates to a vapor generating and superheating unit for maintaining high superheat temperature over a wide load range. More particularly, the invention relates to a high capacity vapor generating and superheating unit in the operation of which superheat temperature is controlled by a flue gas recirculation system directing partially cooled flue gases in regulated quantities along the bottom of a furnace the boundaries of which include vapor generating tubes. The illustrative gas recirculating system directs the recirculated gases into the furnace at a level beneath the level of the burners to present a stream of partially cooled flue gases over the furnace floor and thereby reduce the heat input into the vapor generating tubes constituting a part of the furnace floor. The introduction of flue gases, at some loads, also deflects the burner flames upwardly and thus further reduces the heat input into the furnace wall tubes adjacent the furnace floor. These effects are attained by the invention as the load decreases, and the opposite effects take place as the rate of vapor generation increases, both effects being operative to simultaneously oppositely change the vapor generating heat input, and the heat input to a convection superheater subject to gas flow from the furnace as to maintain a predetermined temperature of the superheated vapor under varying loads.

In the illustrative unit gas burners are arranged in an upright furnace wall. These burners preferably fire horizontally, and at least some of the burners are disposed at a position near the furnace floor which includes a skeleton of floor cooling and vapor generating tubes connected into the circulation of the unit and covered with ceramic refractory. The gases from the furnace pass across the elements of a convection superheater which without modifying influences, would operate to effect an insufficient final superheated vapor temperature over the lower part of the load range. This undesirable effect is eliminated, in the illustrative unit, by the recirculation of partially cooled gases from a position downstream of the superheater to a position in the rear wall of the furnace opposite the burners. The ports for entry of the recirculated gases into the furnace are preferably disposed at a level slightly below the lower row of fuel burners, and the recirculated gases are directed generally horizontally across the furnace floor and toward the burner wall in such a manner that they sweep the furnace floor. The burners of the illustrative unit may employ natural gas as fuel. This is a fuel which is almost ideal, relative to its pertinent combustion characteristics. The percentage of inert elements in this fuel is very low and the fuel can be burned with a short and substantially non-luminous flame. Luminosity will only occur in case there is a cracking of some of the combustible elements to produce carbon compounds or other compounds which have radiation characteristics. In the burning of fuel oil, the same high efficiency of combustion is not attainable in the same period of time, if at all, because the fuel oil must not only be atomized, but the small atomized particles of oil must then be vaporized before they can combine with the oxygen of the air. This action takes a longer period of time for oil to be burned in the best of burners and the products of the resulting combustions have characteristics different from those resulting from the burning of natural gas.

There is a greater luminosity in the products of the oil combustion, and the particles of this combustion have radiant characteristics greater than those of combustion resulting from the burning of natural gas, but considerably less than the products of combustion resulting from the burning of pulverized coal.

The short flame gas or oil burners of the illustrative unit make it possible to utilize a furnace so constructed that a recirculated gas system can be used as a part of the unit to advantageously accomplish control of the heat absorption by the vapor generating tubes of the furnace to the end that the amount of heat available in the gases flowing from the gas outlet of the furnace to the convection superheater can be controlled to effect an optimum final superheated vapor temperature. The above indicated advantages follow from the fact that oil or gas firing burners may be effectively located relatively close to the bottom of the furnace, inasmuch as there is no problem of cooling particles of incombustibles as occurs with pulverized coal firing. Also, the furnace bottom can be lined with ceramic refractory. The furnace of the illustrative unit preferably involves two layers of ceramic refractory brick above the vapor generating and floor cooling tubes of the furnace bottom. When a furnace with such burners and such a furnace bottom construction is operated in the manner suggested for prior installations and without a recirculated gas system, the intense heat of the combustion zone developed by the lowermost burners results in a high degree of radiant heat transfer to the ceramic floor covering. This would normally bring the ceramic floor covering to a state of incandescence and there would be continual extraction of heat from the ceramic floor covering by the subjacent floor cooling tubes, for vapor generation in the latter.

In the method of operation of the invention, with a unit providing for the introduction of partially cooled and recirculated gases into the furnace, and the direction of those gases acorss the furnace in such a manner that they sweep the furnace floor toward the burner wall the distribution of heat by those gases from the faces of the ceramic brick floor covering takes place by convection heat transfer. This transfer of heat from the ceramic bricks lowers the temperature thereof far below the temperature obtaining when the bricks are in an incandescent state and thus decreases heat transfer to the vapor generating tubes which are disposed in heat relationship with the bricks, or equivalent ceramic floor covering. This is one of the factors involved in effecting a greater heat content in the gases leaving the furnace, and contributing to greater convection heat transfer in the superheater. The illustrative introduction of recirculated gases substantially horizontally across the furnace floor carries them on to the burner wall and then upwardly. This action has a tendency to deflect the products of combustion directly issuing from the short flame burners, upwardly. These newly developed products of combustion and the recirculated gases then flow upwardly through the furnace at a velocity greater than the velocity which would be the case if there were no recirculated gases introduced. Thus the residence time and the radiant transfer of heat from the gases to the furnace walls, in the gas flow from the burner zone to the furnace exit, are reduced.

The invention will be concisely set forth in the appended claims, but for a more complete understanding of the invention and its advantages, recourse should be had to the following description which refers to the accompanying drawings.

In the drawings:

FIG. 1 is a sectional side elevation of an illustrative unit including the pertinent superheat control gas recirculation system,

FIG. 2 is a detail horizontal section on the line 2—2 of FIG. 1, showing a preferred construction by which recirculated gases are directed through the furnace wall at the bottom of the unit,

FIG. 3 is a detail partial elevation of an extended surface tube construction at the position of 3—3 of FIG. 2,

FIG. 4 is a detail view of a modified arrangement of the tubes at the gas outlet of the gas recirculation system, and

FIG. 5 is a diagrammatic view, or a partial horizontal section, showing another modified arrangement of extended surface tube elements at the outlet of the gas recirculation system.

The furnace of the FIG. 1 unit is fired by a plurality of horizontal rows of oil or gas burners, the positions of such rows being indicated at **12**, **14** and **16**, along the furnace wall **18**. These short flame burners direct streams of fuel and air toward the opposite furnace wall **20**. At full load, or control point load, high furnace gas temperatures are maintained and the furnace gases rise in the furnace **22** to the inlet of the superheater gas pass **24**, thus affording an adequate heat source for the transmittal of vapor generating heat to all of the vapor generating tubes of the walls of the furnace. These vapor generating tubes discharge vapor and liquid mixtures into the drum **26** where vapor (i.e., steam) is separated so it may pass through the circulator tubes **28** and **30** along the roof **32** to superheater inlet headers such as the gas pass side wall headers **34**. From these headers the steam passes through side wall tubes along opposite sides of the gas pass **36** to the intermediate side wall headers **38**, which are preferably joined by a rear wall header **40**. The header or header section **40** also receives steam (or vapor) through the rear wall tubes **27** disposed along the rear wall of the gas pass **36**, and having their upper parts **31** extending downwardly from a header **29**. The tube sections **31** lead to a point **33** from which the tubes continue through the roof sections **35**, disposed along the roof of the gas turning space **64** to the rear wall of the gas pass. The header **29** is connected by appropriate circulators **37** to the drum **26**. From the header **40** the vapor passes through tubes **42** through the banks of tubes of the superheater sections **44**, **46**, **48** and **50** to the outlet header **52** of the primary superheater. From this header the vapor passes through a conduit **49** to an appropriate attemperator **51**, and thence through a conduit **53** to the inlet header **54** of the secondary or high temperature superheater **56**. From the upright and serially connected tubes of this superheater the vapor passes to an outlet header **58**, and thence to a point of use such as a high pressure steam turbine. From the exhaust of high pressure steam turbine steam to be reheated for utilization in a low pressure turbine enters the reheater inlet header **60** and passes through rows of tubes **62** to the convection reheater section **64**. From this section the vapor passes to the intermediate header **66** and thence through the tubes **68** to the banks of reheater tubes **70** and **72** located just rearwardly of the secondary superheater **56**. From the serially connected tubes of the reheater sections **70** and **72** the vapor passes to the outlet headers **74** and **78**, and thence to the low pressure turbine.

The superheater is of the convection type which has such inherent characteristics that, as the rate of firing of the furnace, and the consequent rate of vapor generation, decreases, the superheat temperature would decrease to an undesirably low value. This inherent characteristic is overcome, and a desired and predetermined superheat temperature is maintained under decreasing load, by the operation of the illustrative recirculated gas system which introduces and directs recirculated gases through the furnace wall **20** at such a position that they sweep the bottom of the furnace at a level below the level of the lowermost horizontal row of burners **16**. This stratum of partially cooled flue gases imposes a resistance to the radiant transmission of heat to the vapor generating tubes of the floor **80** to decrease the heat absorbed in the vapor generating tubes and render available for superheat a greater proportion of the total heat provided by the burning fuel. When the furnace floor includes one or more layers of ceramic bricks **81** above the floor tubes, and when the recirculated gases sweep across the ceramic floor as in the illustrative unit, heat is directly absorbed by the gases by reason of their contact with the higher temperature ceramic floor covering. This brings the ceramic floor covering to a temperature far below the temperature which the floor covering would have if it were in a state of incandescence. This reduction of the temperature of the ceramic floor covering decreases the amount of heat transferred to the vapor generating tubes of the floor and has thus a double effect in controlling superheat at low loads. This double effect involves a reduction of furnace absorbed heat and a simultaneous increase in the availability of the heat in the gases passing from the furnace gas exit. Superheat is also increased as a result of the increased mass flow of the gases over the convection banks of tubes of the superheater.

As the load, or rate of vapor generation, further decreases, the rate of recirculation of furnace gases is increased to further reduce heat absorption by the lower parts of the furnace wall vapor generating tubes at the bottom of the furnace. Such reduction in furnace wall heat absorption for vapor generation is further increased by the displacement of the burner flames or the streams of burning fuel, upwardly away from the furnace floor **80** and away from the rear furnace wall **20**.

The inlet of the gas recirculation system is connected to a flue **90** leading from the ductwork space above the dust collection hopper **92** at the bottom of the gas pass **36**. The ductwork **94** takes the recirculated gases from the flue **90** to a fan **96**, the outlet of which is connected by a duct **98** leading to distribution ductwork such as that indicated at **100**. Recirculated gases from the duct **98** pass centrally into the ductwork **100** and then divide, passing to the right through a branch **102**, and to the left, through a branch **104**. These branches have outwardly tapering or diverging outlet walls as indicated at **106**—**109**, effecting a distribution of the gases throughout the width of the furnace wall **20**. The outlets of the branches **102** and **104** are separated by a division wall **112**, this construction, with associated ductwork, being such as to minimize a short circuiting or cross flow of gases from one part of the furnace to the other.

In order that the flue gases may be uniformly distributed as they pass between the walls of the furnace tubes **20**, aligned tubes of this wall, such as tubes **120**—**123** have their lower parts bent outwardly of their row alignment, or bent outwardly of the plane of the associated tubes, such as **126**—**129**. To protect the ductwork, including the branches **102** and **104**, from excessive heat radiantly transmitted from the furnace the spaces between the alternate pairs of tubes of the outer row of tubes, such as **120**—**123**, are almost wholly closed by rows of stud plates **130** and **131** which are indicated in FIG. 3. These plates are preferably welded to the pertinent tubes of the outer row, such as **122′** and **123′** of FIG. 3.

In the FIG. 4 modification of the wall tube arrangement at the outlet of the gas recirculation system, alternate wall tubes are bent outwardly as indicated at **134** with the openings thus provided being unobstructed except for stud plates **136** welded to adjoining tubes at the curved portions of the bent out tubes **138**.

In the FIG. 5 modification of the tube arrangement at the recirculated gas system outlet, the tubes **140**–**142** remain in wall alignment with the upper parts of the steam generating tubes along the furnace wall. The lower portions **144** and **146** of alternate tubes are bent outwardly to the position shown, and selected tubes, such as **144** have the spaces between them and the tubes, such as **140** and **141**, obstructed by stud plates **150**–**153**, arranged and constructed as are the stud plates in FIG. 3. With this arrangement distributed gas flow passages, such as indicated by the arrows **156** and **158**, are provided across the width of the wall **20**, between alternate groups of tubes, such as the group containing tubes **140**, **144** and **141**.

The rate of recirculated gas flow may be automatically controlled from a number of variables, including representations of final steam temperature and steam flow. Such influences may be automatically effective by known control systems to change the speed of the fan **96**, or effective for regulating one or more dampers, such as **160** and **162**, to coordinate the recirculated gas flow with changes in rate of vapor generation and changes in final vapor temperature.

The illustrative manner of distribution of the recirculated gases uniformly across the width of the furnace is also advantageous when the furnace involves a division wall made up of upright vapor generating tubes dividing the furnace in equal parts with each part extending over a section of the furnace illustrated by the two recirculated gas outlets of FIG. 2.

In a preferred method of vapor generating and superheating to be effected by the illustrative unit for the purpose of attaining a predetermined and controlled superheat temperature and reheat temperature over a wide load range, the gas recirculating system may be regulated so as to maintain a predetermined steam temperature at the outlet of the reheater, with the temperature of the steam from the superheater outlet header controlled by attemperation. Such a method of vapor generation and vapor heating may be effected by manual control of the damper **160** or the manual control of a rheostat changing the speed of the fan **96** and by the manual control of the cooling fluid entry to the attemperator for the superheater or high pressure steam heater.

The illustrative method may be effected manually in a manner somewhat as illustrated in the Durham application Serial No. 258,962, filed November 29, 1951, now Patent No. 2,830,440, or it may be effected automatically by a control system such as that shown by the Paulison application Serial No. 256,986, filed November 19, 1951, now Patent No. 2,985,152. The type of control mechanismillustrated in the Paulison application is perhaps more appropriate inasmuch as the Paulison application involves reheat and superheat control.

The above indicated preferred method is also applicable in a unit similar to that disclosed in the present application but differing therefrom by having the reheater and the primary superheater disposed in parallel gas passes, subject to the flow of gases beyond the high temperature or secondary superheater.

With the preferred method the reheat surface would be set to give a predetermined reheat temperature at full load and reheat temperatures for other loads automatically effected by the control of gas recirculation. Superheat temperature would be automatically controlled or limited by attemperation, preferably spray attemperation.

In the preferred method, and at a load where the heat carried by the gases passing over the convection surfaces would otherwise be of such an amount as to result in an excessive absorption by the superheating and reheating surfaces the total gas flow is regulated so that the reheater will absorb just sufficient heat to bring the final temperature of steam at the outlet of the reheater to a desired value. This will result in the gas flow over the superheater surface which will increase the superheater absorption to such an extent, that, if uncontrolled, it would give a delivered superheat steam temperature in excess of the optimum temperature. At such loads the preferred method involves a reduction of the temperature of the superheated steam by spray attemperation.

Inasmuch as spray attemperation in the superheated steam stream does not result in a lowering of the thermal efficiency of the associated components of a steam turbine power plant, the preferred method thus attains steam temperature control of both the superheated steam and the reheated steam with reduced plant efficiency.

Inasmuch as the pressure and heat content per pound of the low pressure steam returned to the reheater from the high pressure turbine exhaust decreases with reduction in load while the pressure and heat content per pound of the high pressure steam introduced to the superheater remains substantially constant with a corresponding variation in load; prior suggested methods of generating, superheating, and reheating steam, have given a steam temperature-load graph which sloped down from maximum load to low load for the resultant delivery temperatures from both the superheater and the reheater, and the outlet temperature-load graph for the reheater had a greater slope than the corresponding graph of the superheater. This defect is overcome in the present method by the use of gas recirculation in the load range below the control point to increase the proportion of the total heat remaining in the gases leaving the furnace, and regulating this gas recirculation to maintain the desired reheat temperatures. If this action involves an excess in temperature of steam from the outlet of the superheater, the temperature of the steam is automatically reduced to the desired value by attemperation.

To be more specific, with reference to the preferred method, the flow of recirculated gases through the recirculated gas system illustrated in FIG. 1 is preferably automatically controlled by appropriate devices in order to maintain a desired steam temperature at the outlet of the reheater **64**. The predominant influence is the change in rating or load, as represented by changes in steam flow-air flow, this influence being modified as desired, by changes in reheat final steam temperature and superheat final steam temperature.

The preferred method would involve an automatic control of attemperation, such control being predominantly influenced by change in load or rating, or by final steam temperature at the outlet of the superheater, modified particularly by changes in superheated steam temperature when the reheater and the primary superheater are in separate parallel gas flow passes.

Another method of operation, within the purview of the invention, involves the operation of the fan for the recirculating gas system over the entire load range. With this operation, in the type of reheater-superheater unit disclosed herein, the unit is so set that, at full load, or at a certain control point load, a predetermined steam temperature at the reheater outlet would be attained. Any excess temperature of the steam from the high pressure superheater would be reduced by attemperation. Then, as the load decreases toward low load, the flow of recirculated gas would increase somewhat by reason of the reduced flow of newly developed combustion gases consequent to the reduced firing rate of the burners. Furthermore, the ratio of the weight of recirculated gases to the weight of newly developed gases issuing directly from the burners would be increased as the load decreases, to promote superheat control when combined with the effect of attemperation upon the final steam temperature of the superheated steam.

By way of completing a description of the pressure parts of the illustrative unit, FIG. 1 discloses a lower side wall header **170** from which a row of closely arranged furnace side wall vapor generating tubes **172** extend to the upper header **174**. From the latter header, various circulators, such as **176** and **178**, extend to connection with the drum **26**. A similar construction is embodied in the opposite side wall.

FIG. 1 also shows the vapor generating tubes for the rear wall **20** as having their upper ends connected to another header **180** from which some vapor generating tubes continue directly upwardly past the inlet to the gas turning space **182**, to the header **184**. From this header vapor and liquid mixtures are conducted through the circulators **186** to the drum **26**.

Upper extensions of some of the tubes along the wall **20** have upwardly and inwardly extending parts **190** extending along the under side of the arch **192** and thence in screen formation in two rows in front of the secondary superheater **56**, as indicated at **194** and **196**. Others of the tubes extending along the lower side of the arch **192** are disposed in spaced relation along the upwardly inclined surface which forms the stepped bottom **198** of the lateral superheater gas pass **24**. These tubes continue upwardly past the inlet to the gas turning space **182** and then they continue along the roof **200** of the superheater gas pass and the furnace **22**.

All of the pressure parts are enclosed within an appropriate insulating casing, including the bottom section **202**, a front wall section **204**, the roof **32** and the rear section **206**, as well as appropriate side walls.

Whereas the invention has been described with reference to the details of an illustrative embodiment, it is to be appreciated that the invention is not limited to use in which all of those details are involved. The invention may rather involve the use of selected details with the omission of some of the remaining details. The invention is to be considered as of a scope commensurate with the scope of the subjacent claims. Certain features of the present invention are disclosed in my prior copending application S.N. 167,073, filed June 9, 1950, which issued on March 13, 1956 as U.S. Patent 2,737,931.

What is claimed is:

1. In a vapor generating and superheating unit having vertical walls and a closed uniplanar inclined floor arranged to define a furnace chamber of rectangular horizontal cross-section closed at its lower end, vapor generating tubes arranged to fluid cool said inclined floor, a plurality of fluid fuel burners mounted in the vertical furnace chamber wall at the upper end of said floor and arranged to discharge combustible mixtures substantially horizontally superjacent said inclined floor towards the opposite furnace chamber wall, a convection gas pass arranged to receive heating gases from said furnace chamber at a location remote from said fuel burners, and a convection heated vapor superheater in said gas pass, the method of increasing the vapor superheat temperature at low unit operating loads which comprises withdrawing relatively cool heating gases from said gas pass downstream of said superheater and introducing the withdrawn gases through the vertical furnace chamber wall at the lower end of said inclined floor at a level below the lowermost level of said fuel burners and in a stream directed in a manner to sweep along and over substantially the entire area of said inclined floor and towards said fuel burner means so that the radiant heat absorption of said furnace chamber floor cooling tubes is substantially reduced.

2. A vapor generating and superheating unit having vertical walls and a closed uniplanar inclined floor arranged to define a furnace chamber of rectangular horizontal cross-section closed at its lower end, vapor generating tubes arranged to fluid cool said inclined floor, a plurality of fluid fuel burners mounted in the vertical furnace chamber wall at the upper end of said floor and arranged to discharge combustible mixtures substantially

horizontally superjacent said inclined floor towards the opposite furnace chamber wall, a convection gas pass arranged to receive heating gases from said furnace chamber at a location remote from said fuel burners, a convection heated vapor superheater in said gas pass, and means for increasing the vapor superheat temperature at low unit operating loads which comprises means for withdrawing relatively cool heating gases from said gas pass downstream of said superheater and introducing the withdrawn gases through the vertical furnace chamber wall at the lower end of said inclined floor at a level below the lowermost level of said fuel burners and in a stream directed to sweep along and over substantially the entire area of said inclined floor and towards said fuel burner means so that the radiant heat absorption of said furnace chamber floor cooling tubes is substantially reduced.

3. A vapor generating and superheating unit having vertical walls and a closed uniplanar inclined floor arranged to define a furnace chamber of rectangular horizontal cross-section closed at its lower end, vapor generating tubes arranged to fluid cool said inclined floor and vertical walls, a refractory covering on said floor tubes arranged to receive radiant heat from said furnace chamber, a plurality of fluid fuel burners mounted in the vertical furnace chamber wall at the upper end of said floor and arranged to discharge combustible mixtures substantially horizontally superjacent said inclined floor towards the opposite furnace chamber wall, a convection gas pass arranged to receive heating gases from said furnace chamber at a location remote from said fuel burners, a convection heated vapor superheater in said gas pass, and means for increasing the vapor superheat temperature at low unit operating loads which comprises means for withdrawing relatively cool heating gases from said gas pass downstream of said superheater and introducing the withdrawn gases through the vertical furnace chamber wall at the lower end of said inclined floor at a level below the lowermost level of said fuel burners and in a stream directed to sweep along and over substantially the entire area of said inclined floor and towards said fuel burner means so that the radiant heat absorption of said refractory covering and floor tubes is substantially reduced.

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