

[72] Inventors **Walter P. Gorzegno**
Florham Park;
William D. Stevens, North Caldwell; Jan L.
Friedrich, Pompton Plains, N.J.
 [21] Appl. No. **794,629**
 [22] Filed **Jan. 28, 1969**
 [45] Patented **Jan. 19, 1971**
 [73] Assignee **Foster Wheeler Corporation**
Livingston, N.J.
a corporation of New York

3,237,612 3/1966 Koch et al. 122/406
 3,343,523 9/1967 Gorzegno et al. 122/406

OTHER REFERENCES

The Babcock and Wilcox Co., *Steam—Its Generation and Use*, 37th Edition, 5th Printing, copyright 1963, Chapter 11 pages 11–25, 11–26, 11–27. TJ 315. B2 A3 copy also available in Group 344.

Primary Examiner—Kenneth W. Sprague
Attorneys—John Maier, III and Marvin A. Naigur

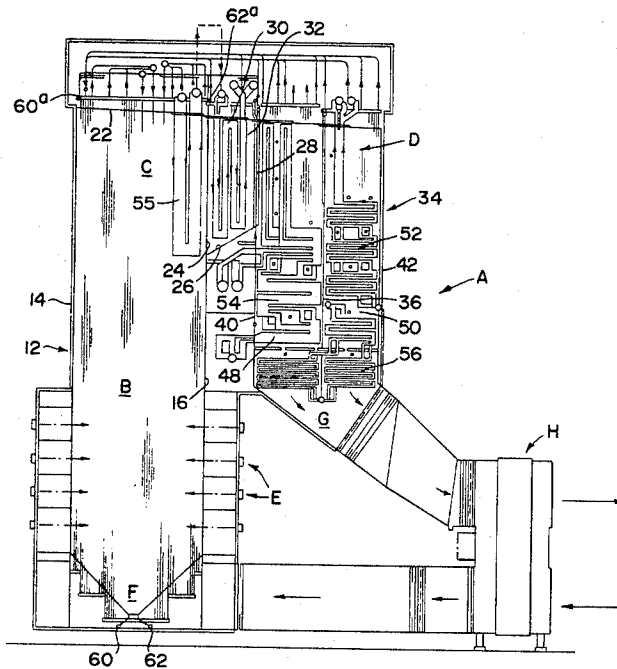
[54] TWO-PASS FURNACE CIRCUIT ARRANGEMENT FOR ONCE-THROUGH VAPOR GENERATOR

14 Claims, 15 Drawing Figs.

[52] U.S. Cl. 122/406
 [51] Int. Cl. F22d 7/00
 [50] Field of Search. 122/235C,
 235S, 406, 406S, 406SU

[56] **References Cited**
UNITED STATES PATENTS
 2,416,053 2/1947 Grossman. 122/235—S
 3,060,908 10/1962 Brister et al. 122/235—C

ABSTRACT: A supercritical forced flow, once-through vapor generator comprising a radiantly heated rectangular furnace enclosure including a lower high-absorption burner zone and an upper gas exit, the generator further comprising a convection heat transfer area in gas flow communication with said gas exit. The periphery of the furnace enclosure at least in the lower high-absorption burner zone is comprised of two upflow fluid passes in series, the first fluid pass comprising opposed front and rear wall panels of the enclosure and the second fluid pass comprising opposed sidewall panels of the enclosure, the enclosure being designed to limit the supercritical fluid enthalpy pickup therein by utilizing the maximum permissible flue gas temperature at said gas exit for the fuel fired.



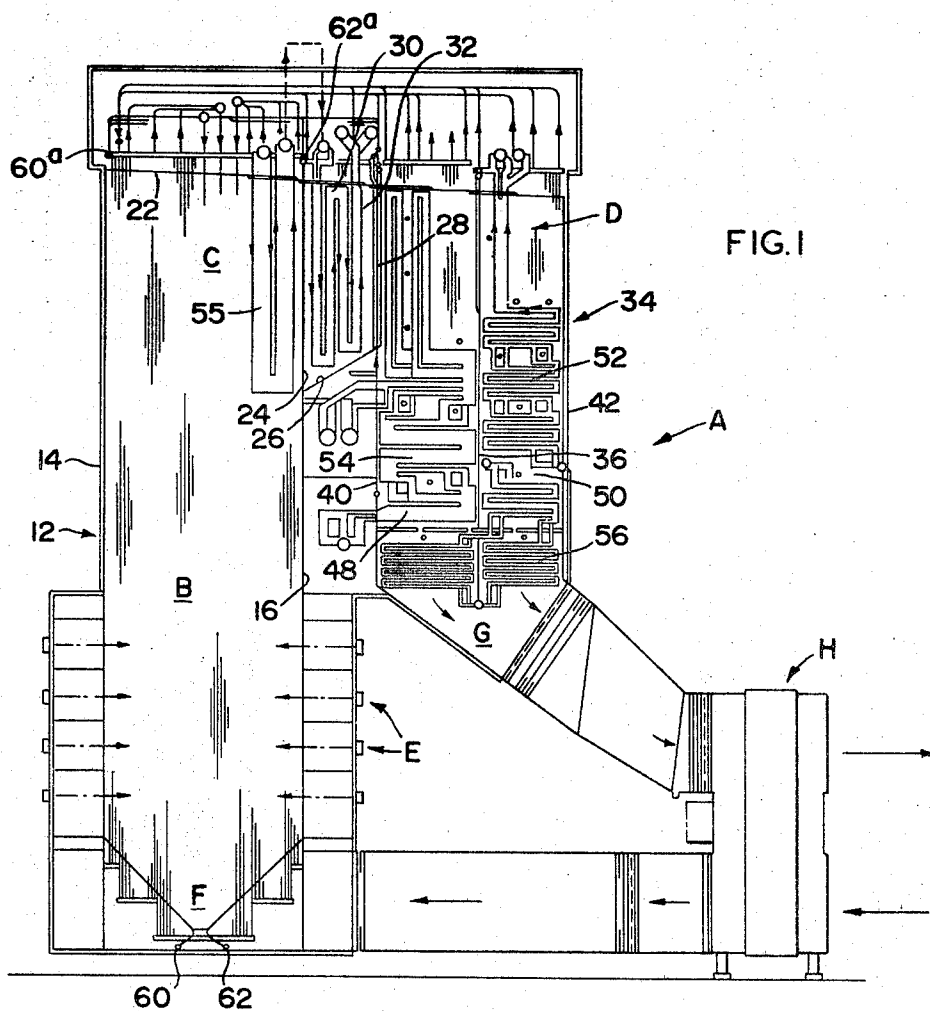


FIG. 1

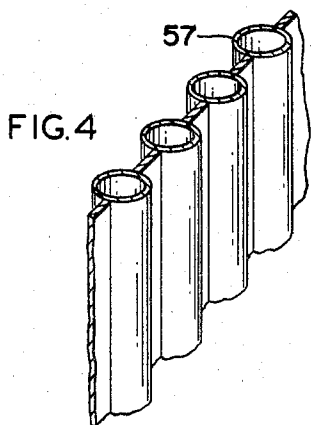


FIG. 4

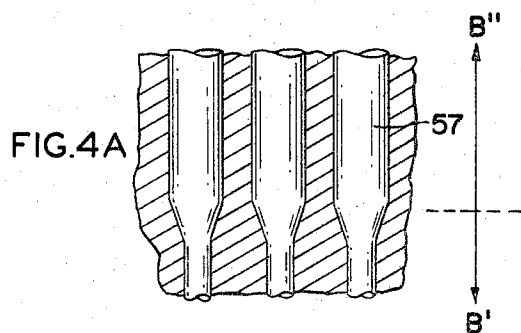
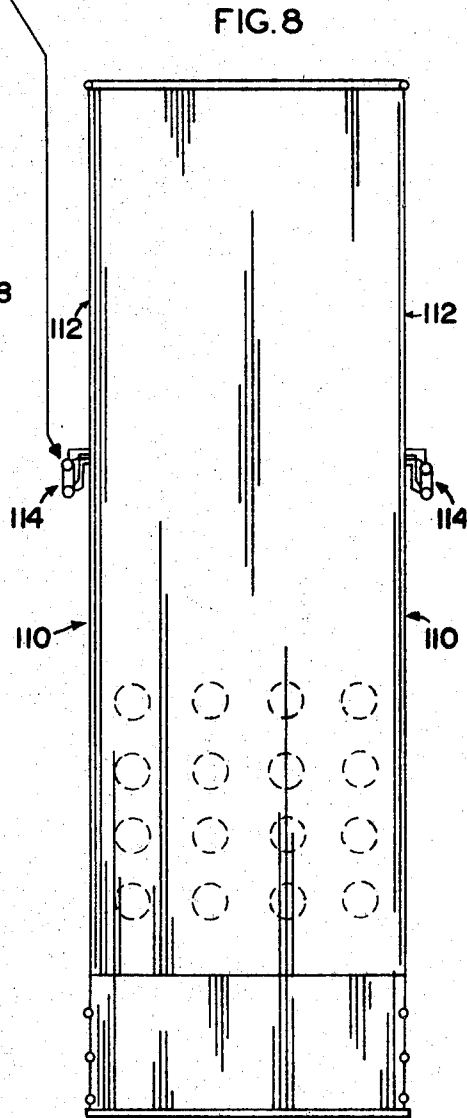
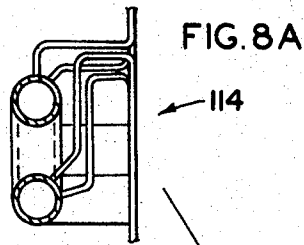
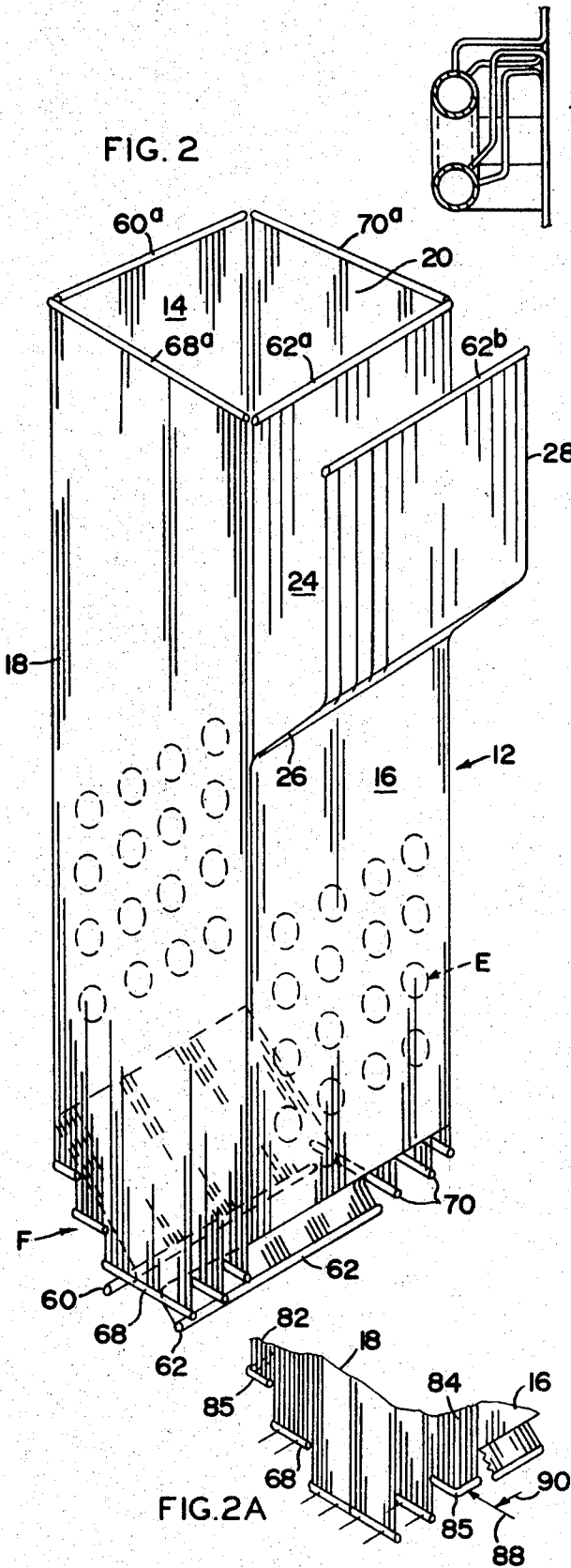


FIG. 4A

INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH



INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

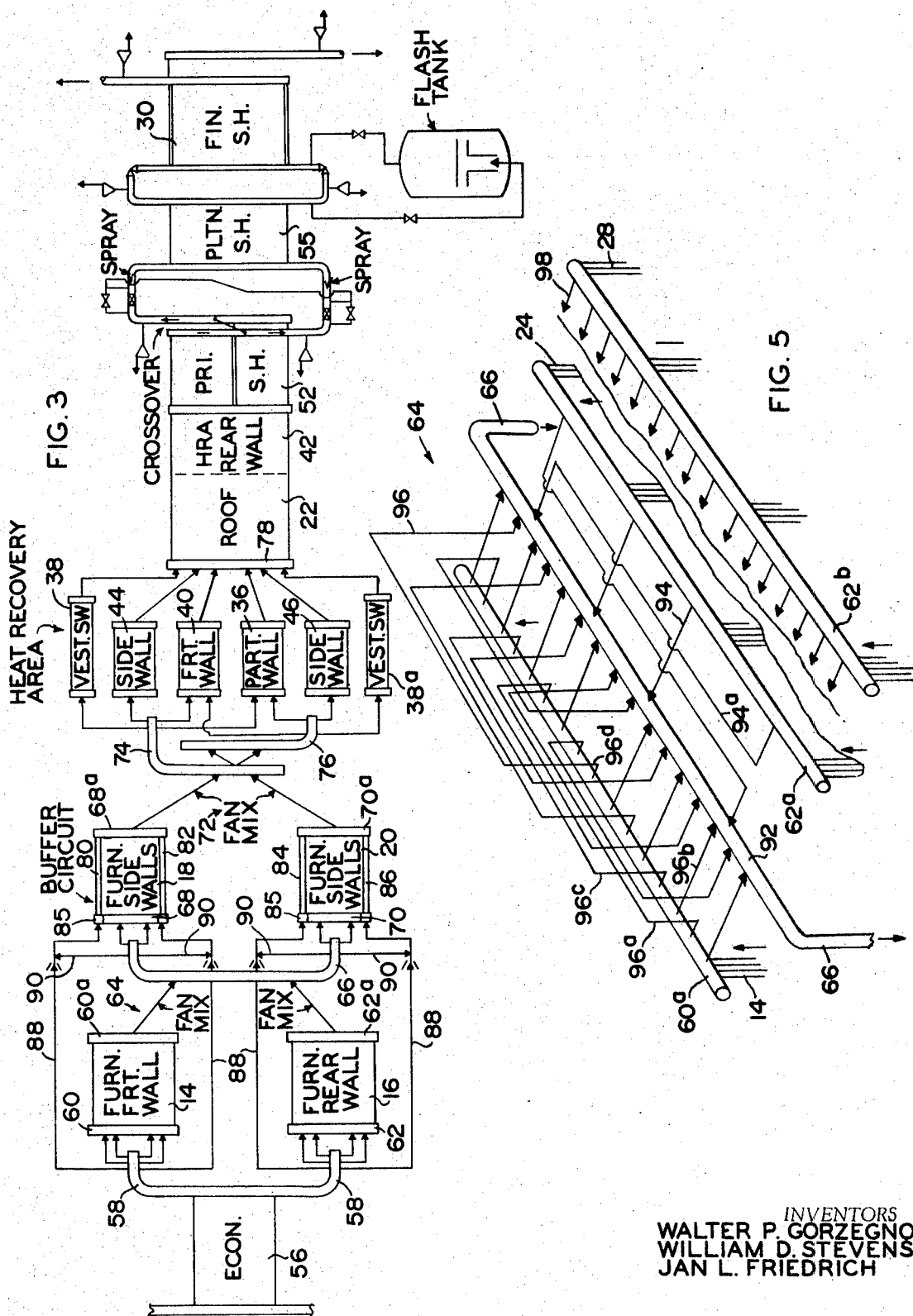


FIG. 5

INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

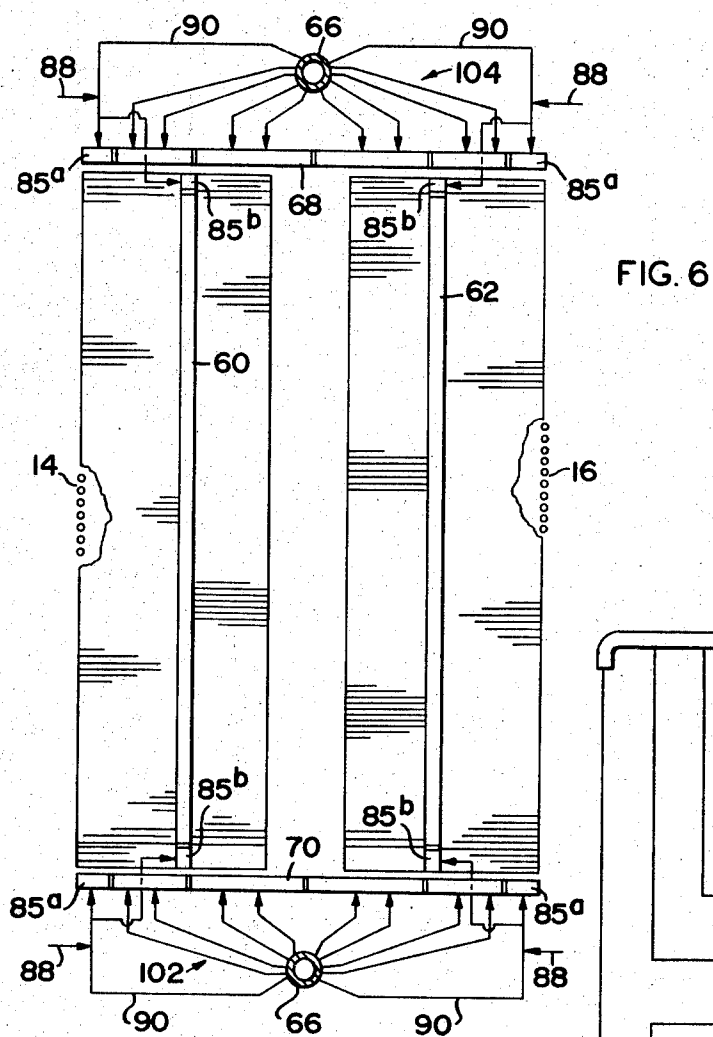
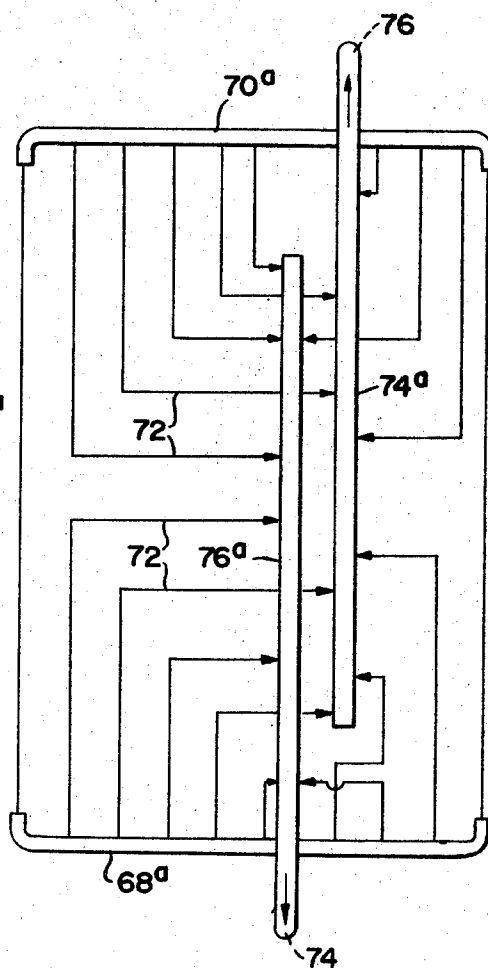


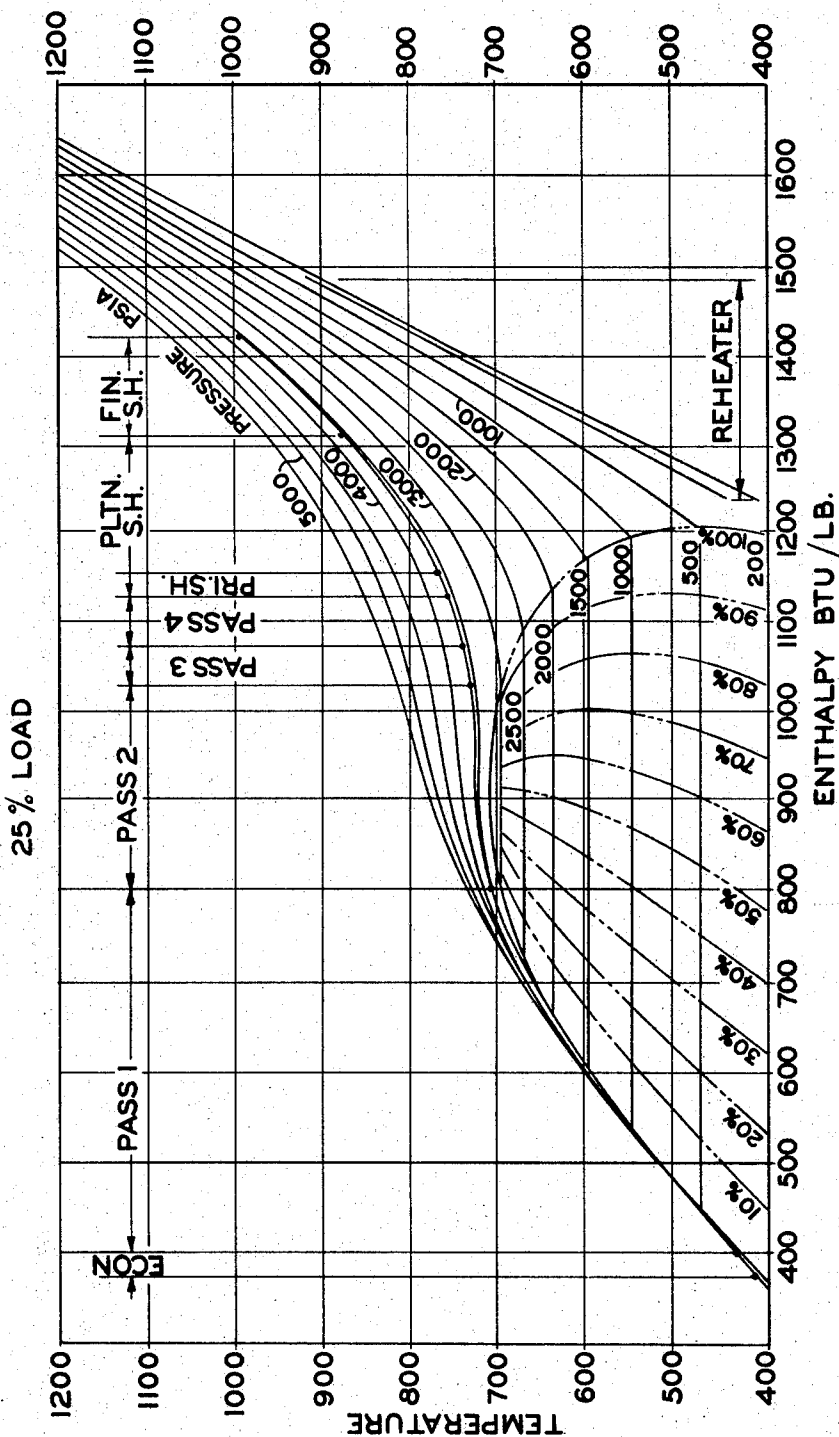
FIG. 6

FIG. 7



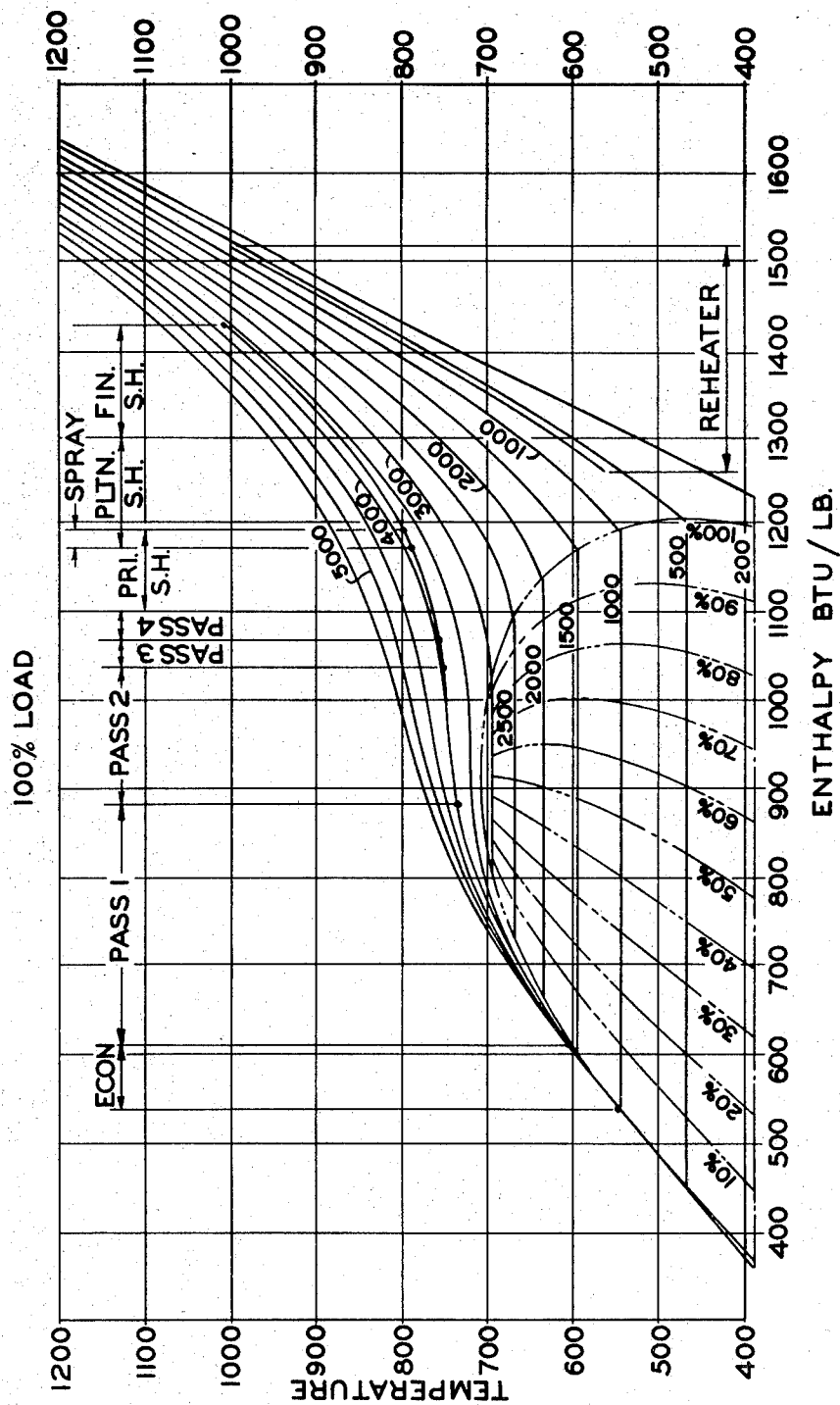
INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

FIG.9



INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

FIG. 10



INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

FIG. 11

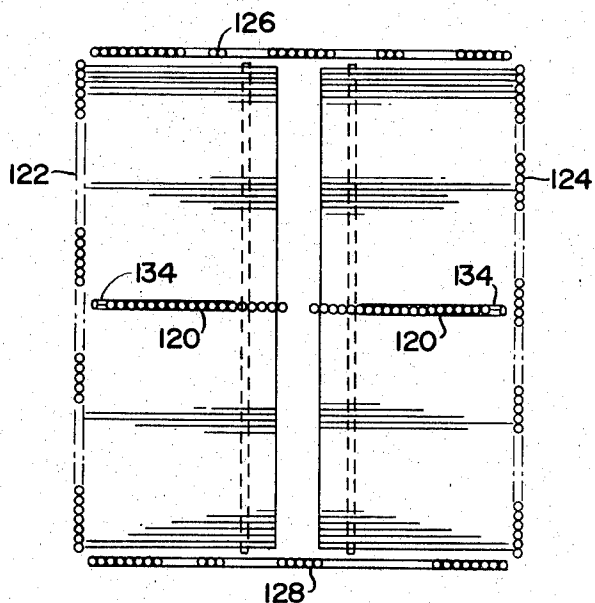
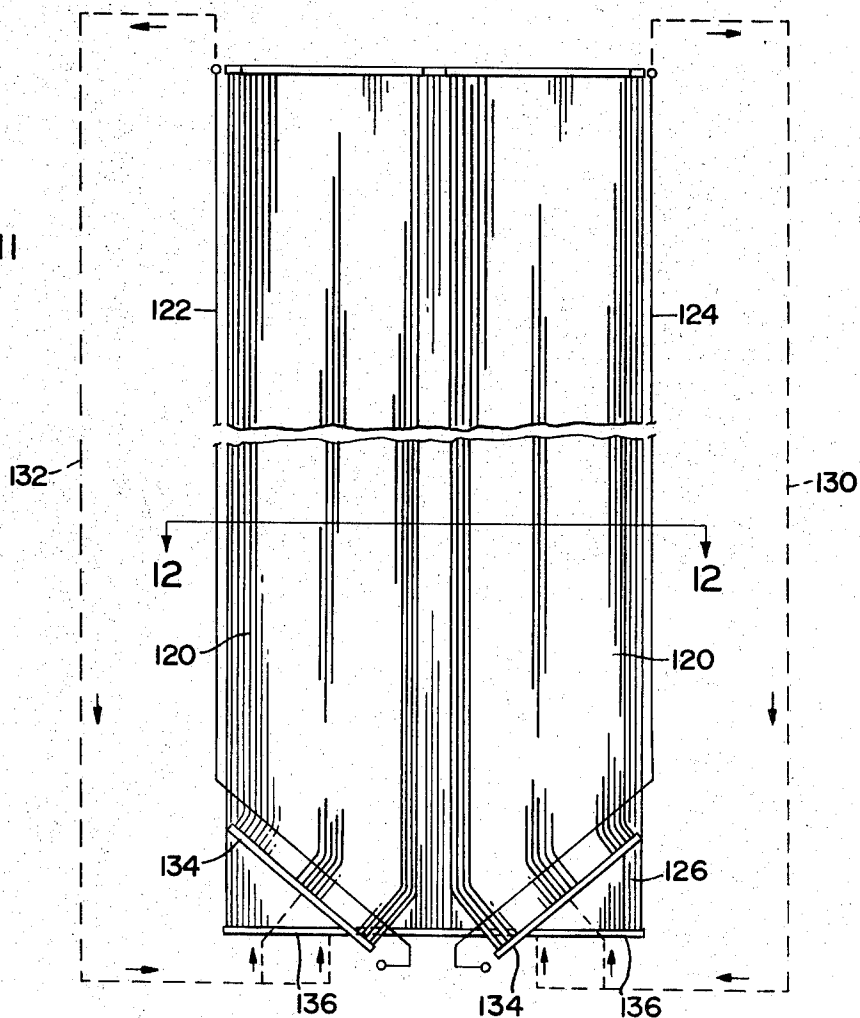


FIG. 12

INVENTORS
WALTER P. GORZEGNO
WILLIAM D. STEVENS
JAN L. FRIEDRICH

TWO-PASS FURNACE CIRCUIT ARRANGEMENT FOR ONCE-THROUGH VAPOR GENERATOR

DESCRIPTION

The present invention relates to vapor generators, and in particular to vapor generators of the once-through type.

The invention is particularly applicable to the "Benson" type once-through vapor generator design, and will be described with reference thereto, although it will be appreciated that the invention has broader application, such as with the Sulzer design or with the recirculation type of generator.

The invention also is particularly applicable to a supercritical once-through vapor generator.

A once-through vapor generator of the "Benson" design is one wherein the fluid flow is forced through tubes of the generator without fluid recirculation. The basic circuitry of the this "Benson" design consists of heated upflow tubes coupled to unheated downcomers. In once-through vapor generators of past years, the fluid flow was transmitted frequently in at least a single first-flow pass defining the entire perimeter of the generator furnace enclosure walls, to passes making up the remainder of the furnace and convection enclosure circuitry of the generator, the convection enclosure area including superheating passes, and from there to a point of use, all of the passes being connected in series with each other. The convection area usually extended from the top of the furnace enclosure, and burners for the generator were disposed near the bottom of either or both of the front and rear walls of the enclosure.

Once-through vapor generators are becoming larger in capacity and dimension, present generators having a furnace enclosure of very large dimension, with a large number of burners disposed in opposite front and rear walls of the enclosure. Because of this large size, special precautions have to be taken to insure equal heat input distribution and correspondingly equal distribution of fluid flow in tubes of the furnace enclosure. For instance, tubes in the center of a furnace enclosure wall may experience more heat absorption than tubes in the corner of the enclosure, resulting in unequal temperatures in the periphery of the enclosure and an imbalance in the flow. This imbalance, could result in a relatively stagnant flow in part of the enclosure, in turn quickly resulting in tube overheating.

In general, parallel tube forced flow circuits where fluid enthalpy pickup is large exhibit greater sensitivity to flow imbalance caused by heat absorption upset. A furnace pass (fluid circuit) encompassing the entire furnace periphery is more subject to flow imbalance, because the enthalpy pickup is usually correspondingly greater, and the geometry of the pass arrangement imposes greater absorption heat upsets.

A member of different approaches have been taken in the past to reduce or overcome the problem of sensitivity of a furnace circuit to heat absorption upset. One approach used has been to recirculate part of the fluid flow leaving the furnace back to the furnace inlet end. The furnace circuit when this approach has been used has consisted of a single flow pass encompassing the entire furnace periphery. An increase in the fluid weight flow through the pass by recirculation maintains fluid velocities at lower loads and reduces fluid enthalpy pickup in direct relation to the quantity recirculated. This approach has the disadvantage in that it increases pumping costs and power losses to pump the recirculated fluid, and also adds to maintenance requirements.

In addition, recirculation is usually not economical at full load operating condition, so that the furnace at full load operates with substantial fluid enthalpy pickup plus the necessity to distribute fluid flow and heat absorption to the full furnace periphery.

It has also been proposed to limit the enthalpy pickup in the furnace enclosure, and thereby reduce the danger of a flow imbalance caused by differences in tube enthalpy pickups, by recirculating flue gases to the enclosure. The cooler flue gases

mix with the burner gases lowering the gas temperatures in the furnace, in turn lowering furnace absorption, and the resulting fluid enthalpy pickup. Gas recirculation however has the obvious disadvantage in that it increases equipment construction, operating and maintenance costs.

A further proposal has been to divide the furnace enclosure into a plurality of parallel oriented upflow heated passes, each comprised of parallel tubes, with means to connect the passes in series and distribute the flow uniformly to the tubes of the passes. Each pass has a fewer number of parallel tubes, and correspondingly less fluid enthalpy pickup reducing the likelihood of a flow upset in any one pass. This design also makes possible higher fluid mass flow rates within the tubes, without fluid recirculation, yielding a more conservative lower tube metal temperature. These parallel oriented upflow heated furnace passes connected in series, with unheated downcomers between the passes, adhere to the concept of the "Benson" principle of design.

Inherently the above arrangement of many furnace passes in series results in increased capital costs in manufacture and construction for the generator because of the size and number of downcomers, headers, and connection pipes. For instance, the downcomers and connection pipes associated therewith required between the multiple flow passes in series, add to the length of the fluid flow path. Because of this added flow path length, the downcomers and connection pipes, and in some cases headers, must be sized sufficiently large to limit the fluid pressure drop to within acceptable limits.

A factor which also complicates the use of the multipass design is the all-welded wall construction in which parallel finned tubes are welded together along their lengths to provide a gastight enclosure. Although this construction has resulted in substantial savings in construction costs, eliminating the use of complex casing designs, it has meant that the passes must be arranged so that adjacent tubes are at roughly the same temperature to avoid fracture of the connections between the tubes, or of the tubes themselves, caused by thermal stresses resulting from the restrained growth of one tube relative to another during load changes in the generator.

As a rule of thumb, a 100° F. to 125° F. maximum tube temperature difference is allowed between adjacent tubes of an all-welded generator furnace enclosure.

In accordance with the invention, there is provided a once-through supercritical forced flow vapor generator comprising a radiantly heated rectangular furnace enclosure including a lower high-absorption burner zone and an upper gas exit, the generator further comprising a convection heat transfer area in gas flow communication with said gas exit; the periphery of the furnace enclosure at least in the lower high-absorption burner zone being comprised of two upflow fluid passes in series, the first fluid pass comprising opposed front and rear wall panels of the enclosure, the second fluid pass comprising opposed sidewall panels of the enclosure; the enclosure being designed to limit the supercritical fluid enthalpy pickup therein by utilizing a flue gas temperature at said gas exit of substantially the maximum permissible for the fuel fired.

By the term "maximum permissible flue gas temperature", it is meant the upper design limit for the flue gas temperature at the furnace gas exit. The particular design value for this limit varies depending primarily upon the fuel fired, but for a particular fuel, and defined conditions, the limit generally is fixed and well known. In the case of a gas-fired unit, the accepted limit is about 2800° F, above which the residence time in the furnace may be so short as to preclude complete combustion in the furnace; and above which the cost for alloy tubes in; for instance, a superheater circuit adjacent the gas exit becomes economically unattractive. In the case of oil firing, vanadium attack on metals in the convection zone sets the limit at about 2650° F. For coal, the limit is even lower, less than about 2350° F., depending on the grade of coal, above which slagging at the flue gas exit can occur. It is of course understood that the above values may vary somewhat depending upon a number of factors, and that these values are only representative.

In designing to obtain a maximum permissible flue gas exit temperature, the generator furnace surface is sized so that the furnace heat absorption, or fluid enthalpy pickup within the furnace circuits is correspondingly small. Limiting the total furnace circuit enthalpy pickup has the result that in a two-pass furnace circuit the enthalpy pickup for each pass is sufficiently low to obtain stable circuit characteristics i.e., less likelihood of a flow imbalance in the presence of a heat absorption upset.

In addition, by so limiting the size of the furnace enclosure, the furnace geometry, defined as distribution of flow passes and selection of tube sizes, can be set so as to obtain the high mass flow rates necessary to render the furnace circuitry relatively insensitive to flow imbalance; that is, sufficient mass flow to obtain proper cooling of the tubes even where considerable heat absorption upset and flow imbalance occur.

It will become apparent that this optimum circuit characteristic is obtained without the need for either gas recirculation, or recirculation of the supercritical fluid back to the inlet end of the furnace circuitry.

It will also become apparent that the use of only two upflow fluid passes in the furnace circuitry considerably simplifies the generator design and reduces construction costs, for instance, in eliminating connections, downcomers, and field welding.

As a further advantage, by limiting the supercritical fluid enthalpy pickup in the furnace to about the minimum permissible, the log-mean temperature difference between the heating flue gases and supercritical fluid in the convection superheater and reheater is increased, correspondingly increasing the efficiency of heat transfer for these surfaces. This permits these expensive surfaces to be reduced in size, which has the affect of reducing costs and in addition increasing the generator overall rating (defined as B.t.u./hr.-/sq. ft. of surface area).

Preferably, in accordance with an aspect of the invention, the burners for the generator are disposed in both the opposite front and rear walls of the first pass of the furnace enclosure. In this way, the coolest tubes face and are adjacent to the burners, for maximum safety against tube overheating.

Also, in accordance with a preferred aspect of the invention, the furnace circuitry comprises a buffer circuit between the front, rear and sidewall panels of the first and second passes including a plurality of parallel vertically oriented tubes disposed in the corners of the furnace enclosure between the panels. Header means are provided to direct a sufficient portion of the flow from the inlet ends of both the first and second passes to the buffer circuit tubes so that the average temperature in the buffer circuit is maintained intermediate the temperatures in the first and second passes. In this way, the affects of thermal stresses in the all-welded enclosure between adjacent tubes of the first and second passes are minimized.

It is also preferred in accordance with the invention to provide a furnace enclosure in which the tube diameters in the first and second pass panels in the upper portions thereof are enlarged reducing the mass flow rates and pressure drops in these passes, but still maintaining mass flow rates at levels acceptable for safe operation.

It is further preferred in accordance with the invention to provide fan-mix connections between outlet headers for the panels of the first and second passes and downcomer means leading to subsequent passes to fully mix the flow in order to obtain a uniform temperature distribution at the inlet ends of the subsequent pass panels.

Accordingly, it is an object of the present invention to provide a generator circuit design in which the disadvantages of prior designs are overcome; and in particular a generator design of simplified concept which is functionally equivalent or superior to past designs. By functionally equivalent, it is meant a circuit design which has a minimal fluid enthalpy pickup per pass and which by virtue of furnace pass geometry (including pass distribution and tube sizing) is relatively insensitive to flow imbalance caused by heat upset.

It is a further object of the present invention to provide a generator construction and design which is simpler and less

expensive than those used heretofore, and in particular, which is less expensive to erect, requiring fewer field welds and minimum connecting piping and downcomers.

The invention and advantages thereof will become more apparent upon further consideration of the following description, with reference to the accompanying drawings, in which:

FIG. 1 is a section elevation view of a vapor generator in accordance with the present invention;

FIG. 2 is a schematic perspective view illustrating the furnace circuits and construction of the generator of FIG. 1 in accordance with the present invention;

FIG. 2A is a perspective partial view further illustrating the furnace circuits and construction of the generator in accordance with an embodiment of the invention;

FIG. 3 is a flow diagram illustrating the concepts of the present invention;

FIG. 4 is a perspective view of a portion of a tube wall section in accordance with the present invention;

FIG. 4A is an elevation view of a furnace tube wall surface in accordance with the invention;

FIG. 5 is a schematic perspective view of a header and a downcomer manifold arrangement in accordance with the invention taken at the top of the furnace portion of the generator of FIG. 1;

FIG. 6 is a schematic plan view looking upwardly taken of the bottom of the furnace portion of the generator of FIG. 1;

FIG. 7 is a further schematic plan view taken at the top of the furnace portion of the generator of FIG. 1, further illustrating the concepts of the present invention;

FIG. 8 is an elevation front wall view of the furnace portion of the generator illustrating an embodiment of the invention;

FIG. 8A is an enlarged section view of a portion of the generator of FIG. 8;

FIGS. 9 and 10 are graphs of fluid temperature vs fluid enthalpy illustrating concepts of the invention; and

FIGS. 11 and 12 are schematic elevation and section views illustrating a further embodiment in accordance with the invention.

Turning to the FIGS., the vapor generator in accordance with the present invention is broadly indicated with the letter A, and comprises a vertically extending rectangular shaped radiant furnace portion B having an upper exit end C to which is connected to a horizontally extending and downwardly extending convection area D. Burners E are disposed in the furnace portion immediately above a bottom hopper F. The flow of hot gases is upwardly in the furnace portion through the convection area of the generator to the generator outlet end G and from there to a conventional air heater H for heat exchange between the hot gases and incoming air for the burners.

The present invention is concerned primarily with the flow circuitry for the high-pressure fluid which is in heat exchange with the burner gases.

Turning to FIGS. 1 and 2 in particular, the vapor generator furnace portion is an upright rectangular enclosure 12 defined by front and rear walls 14 and 16 between which are disposed sidewalls 18 and 20, the enclosure extending vertically from the bottom hopper F to a roof 22 (FIG. 1). Immediately beneath the roof 22, the rear wall 16 is divided or branched to provide an exit screen 24 leading to the convection area D of the generator, and a floor 26 leading to a second screen 28, these last two items with the exit screen 24 constituting an enclosure which encompasses tubes of a finishing superheater, item 30, to be described. By bending a selected number of tubes from the rear wall for the enclosure floor 26 and screen 28, there is adequate spacing across the exit screen 24, as well as screen 28, for the flow of hot gases.

In the convection area D, frequently referred to as the heat recovery area, the generator comprises an intermediate vestibule portion 32 followed by a downwardly extending convection enclosure 34. The vestibule enclosure in addition to floor 26 comprises opposed sidewalls, not shown in FIGS. 1 and 2, whereas the convection enclosure 34 comprises a parti-

tion wall 36, a front wall panel 40 extending downwardly from the floor 26, a rear wall panel 42, and sidewalls (also not shown). The partition wall 36 divides the convection enclosure 34 into front and rear gas passes 48 and 50. As shown, the roof 22 extends not only above the furnace enclosure 14 but also above the vestibule 32 and convection enclosure 34.

Within the vestibule 32 and convection enclosure 34, encompassed by the heat recovery area tubes as defined above, are a primary superheater 52, within the enclosure rear pass 50; the finishing superheater 30 encompassed by the furnace second pass screen tubes 24 and 28; plus banks of reheater tubes 54 in the enclosure front pass 48. Economizer tubes 56 are disposed in both passes 48 and 50, beneath the primary superheater and reheater banks, and completing the circuitry is a radiant platen superheater 55 positioned in the furnace upper portion adjacent to and in front of the furnace exit screen 24.

It is a feature of the invention that a membrane-type wall construction illustrated in detail in FIG. 4 will be used substantially throughout in walls of the generator, formed by welding together a plurality of finned tubes 57 along their lengths so that the enclosures are substantially gastight. By virtue of the membrane-type wall construction, use of the conventional refractory and casing-type constructions, with accompanying costs, is substantially avoided.

The flow circuitry in accordance with the present invention is illustrated in FIG. 3. From the economizer 56, a suitable downcomer 58 conveys the flow to inlet headers 60, 62 of the furnace front and rear wall panels 14, 16 for parallel flow therein. As shown in FIG. 2, the headers 60, 62 and panels 14, 16 are substantially coextensive with the furnace front and rear walls, these panels constituting a furnace first-flow pass. Referring back to FIG. 3, from outlet headers 60a, 62a for the front and rear wall panels (at a third header 62b for the second screen tubes 28 is shown in FIG. 2), by means of a fan-mix connection 64, to be described, the flow is transmitted to suitable downcomers 66 on opposite sides of the generator and from there to lower inlet headers 68, 70 for the furnace sidewalls 18, 20. The flow is then parallel upwardly through the furnace sidewalls to upper outlet headers 68a, 70a, exiting via a fan-mix arrangement 72 to downcomers 74, 76 for the heat recovery area. Here, the flow is evenly distributed for parallel flow through the vestibule sidewalls 38, 38a, the convection enclosure 34, front and sidewalls 40, 44, 46, and the partition wall 36, exiting via collecting headers 78 for flow into the roof 22 of the generator and heat recovery area rear wall 42. From the rear wall 42, the flow is in succession through the primary superheater 52, the platen superheater 55, and the finishing superheater 30 to a point of use.

With reference to FIG. 1, it is apparent that the flow is upwardly in the furnace walls, in essentially two vertically oriented upflow flow passes connected in series, each pass comprising pairs of opposed walls. In this way, the panels of each pass are in similar absorption zones, the burners being disposed in the opposite front and rear wall first pass panels 14 and 16. Each wall panel of pass 1 will thereby be subjected to roughly the same radiant heat input from the burner arrangement. Similarly the sidewall panels of pass 2 because of their symmetrical location relative to the burners will receive roughly equal absorption.

It is also a feature of the invention that by positioning the burners in the front and rear walls, the burners are in and face the tubes of the colder first pass, thereby providing added protection against tube overheating in the circuitry.

FIGS. 2A and 3 illustrate a preferred embodiment of the invention. As shown, the corners of the furnace enclosure are made up of tubes of a buffer circuit, comprising four corner panels 80, 82, 84, 86 (only two of which are shown in FIG. 2A) interposed between the front, rear and side panels 14—20 of the first and second passes. Flow into the buffer circuit is accomplished by providing inlet headers 85 substantially coextensive with these corner panels, and transmitting a portion of the flow from the economizer in downcomer 58 (lead-

ing to the furnace front and rear wall headers) via four connections 88 (FIG. 3) to the buffer circuit inlet headers 85. A portion of the flow transmitted to the inlet headers 68, 70 for the sidewall panels, from downcomers 66, is also transmitted to the inlet headers 85 for the buffer circuit panels via four connections 90 (FIG. 3) for mixing with the flow from downcomers 58 and connections 88.

These combined flows produce a fluid flow into the buffer circuit inlet headers which is at a temperature intermediate the inlet temperatures of the first and second pass panels. At the outlet ends of the buffer circuit panels, the flow simply is into the furnace sidewall outlet headers 68a and 70a, for mix with the flow from these walls.

By suitably orificing the connections to the buffer circuit panels, the flow can be balanced between these panels and the first and second pass panels. At certain loads, the temperature at the same elevation in passes 1 and 2 may be in excess of 100° F. apart, and closer to 200° F. apart, with corresponding differences in expansion in the pass tubes if they were free to expand. These restrained expansion differences result in thermal stresses which are at least in part reduced by the use of the buffer circuit panels.

Prior Pat. No. 3,344,777, applied for by Walter P. Gorzegno and assigned to assignee of the present application, describes the concept of a buffer circuit in detail but the improvement of the present invention lies in the fact that the furnace pass circuits occupy substantially the full expanses of the front, rear and sidewalls of the all-welded furnace enclosure, and the buffer circuit panels are disposed in the critical corner areas.

In an example in accordance with the invention, the buffer circuit corner panels may each comprise an expanse (in the furnace periphery) of about 1½ feet of the sidewalls and about five tubes of the front and rear walls, the corners suitably beveled to reduce corner stresses and heat absorption in the corners. Beveling the corners may be accomplished by making the sidewall horizontal dimensions slightly less than the spacing between the front and rear walls so that the latter bend inwardly, at an angle of about 30°, to the sidewalls.

It is desired to maintain high mass flow rates in the furnace pass tubes for reasons to be discussed, but at the same time reduce the furnace pressure drop to a minimum level, the pressure drop increasing with mass flow rate. A solution in accordance with the present invention, is illustrated in FIG. 4A. The furnace zone is divided into a lower high temperature area B' which extends from near the bottom of the furnace to an elevation above the burners, and a lower temperature area B'' constituting the remainder of the furnace above the area B' to the roof 22. As shown, the tube diameters are increased in going from the higher temperature furnace burner zone (area B') to the lower temperature upper furnace zone (area B'').

Although this feature of the invention will be discussed in greater detail, in an example, the front and rear walls or first pass will have 1¼-inch OD tubes in the burner zone changing at an elevation about two-thirds of the height of the furnace to 1½-inch OD tubes. The sidewalls or second pass will have 1¾-inch OD tubes changing at about the same elevation to 1½-inch OD tubes; the center-to-center distance in all the walls being 1¾ inches.

In the buffer circuit panels, the tube diameters may also be increased near the top, for instance from 1¼ inches to 1½ inches.

FIG. 5 illustrates the fan-mix connections 64 between the outlet headers for the front and rear furnace walls and the downcomers leading to the furnace sidewalls. These outlet headers are shown as three parallel members 60a, 62a, 62b disposed at the top of the furnace enclosure 12 into which the tubes of the front wall 14 and rear walls screens 24, 28 extend. It will be recalled that although the tubes of the front wall extend vertically upwardly into the header 60a, the tubes of the rear wall are divided into the exit screen panel 24 and a second panel 28.

A downcomer manifold 92 extends horizontally across the top of the furnace, positioned slightly above the horizontal plane of the headers 60a 62a, 62b and in a vertical plane between the planes of the front and rear walls, the downcomer manifold having a length which is substantially coextensive with the furnace width. This downcomer manifold is connected at opposite ends to the downcomers 66 which lead into the inlet headers 68 and 70 for the second pass sidewall panels.

As illustrated in FIG. 5, the connections 94 between the exit screen header 62a and the downcomer manifold 92 are few in number and lead more or less directly into the downcomer manifold, except that the end connections 94a are crossed to shift the flow from one side to the other of the generator. The reason for the small number of connections 94 is that the flow from the exit screen header will be relatively small. From the front wall header 60a and the second screen header 62b which provide the bulk of the flow into the downcomer manifold 92, the connections 96 and 98 respectively are arranged to disperse and mix the flow. For instance, the fluid collected at one side or end of the front wall header 60a will be dispersed in part to the opposite side of the downcomer manifold, and vice versa for the fluid collected at the opposite end of the header. In addition the fluid collected in the ends of the header 60a will be dispersed in part to the center of the manifold; and vice versa, fluid collected in the center of the header will be dispersed in part to the ends of the manifold. Further there will be flows, from the header 60a directly across to corresponding parts of the manifold.

This can be made clear by tracing particular connections. For instance, a connection 96a from one side and one end of the front wall panel header 60a will extend towards the downcomer manifold 92 and across the top of the furnace to connect with the downcomer manifold near the center of the latter, but on an opposing side. The next connection 96b in the direction of the header center will connect directly across with the manifold, whereas connection 96c further centered on the header will connect with the manifold at a point further removed from the manifold center than the connection 96a; so that ultimately, a connection 96d which extends from near the center of the outlet header will extend across the furnace to near the end of the downcomer manifold.

The same fan-mix arrangement is provided between the downcomer manifold and the second screen header 62b, the connections having essentially the same pattern as those between the front wall header and the downcomer manifold.

It is apparent that there will be a shifting and mixing of the flows from the first pass panels; not only a mixing of the flow from the front wall panel with that of the rear wall panel; but also a shifting and mixing of flows from one side of the furnace across to the other, from the sides of the panels to the center, and vice versa. Accordingly, the side downcomers 66 which lead to the second pass will transmit fluid flows having essentially the same temperature or enthalpy level.

To achieve a uniform flow distribution in the sidewall panels of the second pass, the downcomers 66 leading from the downcomer manifold along the sides of the furnace to the inlet headers 68 and 70 at the bottom of the furnace are provided with fanned connections 102 and 104 (FIG. 6) which lead to these sidewall inlet headers connecting to the latter at spaced points along the headers.

FIG. 6 also illustrates the buffer circuit arrangement, showing inlet headers 85a and 85b of the circuit in each of four corners, and connections 88 and 90 from downcomers leading to the first and second passes, respectively.

In FIG. 7, the fan-mix connections (72, FIG. 3) between the outlet headers 68a and 70a of the second pass sidewall panels (which headers also receive the flow from the buffer circuit panels) and the downcomers 74 and 76 are illustrated. In this example the downcomer manifold is split into two manifolds 74a and 76a, and the connections 72 from each header will alternately lead to the two downcomer manifolds. In this way, each of the manifolds receives half of the flow from each of

the two headers thereby assuring equal enthalpy levels at the inlet ends of the successive flow passes.

It was mentioned that an object of the present invention is to provide a simplified design which is functionally equivalent or superior to past designs. By sizing the predominantly gas and oil-fired furnace so as to produce the highest flue gas exit temperature permitted by good design practice, a stable two-pass furnace design can be constructed without violating conservative design criteria. Two factors contribute to this stability, one being a limited enthalpy pickup per pass, the other being relatively high average mass flow rates, in pounds per hour per square foot, in the furnace tubes.

The limited enthalpy pick up per pass is illustrated in the graphs of FIGS. 9 and 10, which relate enthalpy pickup to temperature. Referring to FIG. 9, which shows the enthalpy temperature increase in the generator at 25 percent load, the enthalpy increase in the first pass is from about 400 to 800 B.t.u.'s per pound, the temperature level in the pass increasing from about 420° F. to about 710° F. In the second pass, the enthalpy level is further increased from about 800 B.t.u.'s per pound to about 1030 B.t.u.'s per pound, the temperature level in this pass increasing from only about 710° F. to about 740° F.

At full load (FIG. 10), in the first pass, the enthalpy level may increase from about 610 B.t.u.'s per pound to about 880 B.t.u.'s per pound, the temperature increasing from about 600° F. to about 730° F. In pass 2, there is a further temperature increase to about 750° F. and an enthalpy increase to about 1040 B.t.u.'s per pound.

These enthalpy pickups or increases in the furnace passes are sufficiently low to provide stable circuit characteristics, rendering a large flow imbalance in the passes less likely in the event of a furnace heat upset.

The following Table I gives representative mass flow rates for the first and second passes and boundary wall heat recovery area third pass, in accordance with the invention.

TABLE I

Location	Average mass flow rate, lb./hr., sq. ft. (Representative avg. values)
Pass (1) (Front and Rear Walls):	
Lower Furnace (1½" OD tubes)	G=2.36×10 ⁶
Upper Furnace (1½" OD tubes)	G=1.54×10 ⁶
Pass (2) (Side Walls):	
Lower Furnace (1½" OD tubes)	G=2.45×10 ⁶
Upper Furnace (1½" OD tubes)	G=2.12×10 ⁶
Pass (3) (Heat Recovery Area Boundary Walls)	G=0.74×10 ⁶

In accordance with the invention, these mass flow rates are sufficient to render the passes relatively insensitive to a flow upset, so that should a small flow imbalance occur in one of the passes, the tubes of the pass still will be adequately cooled by the high mass flow rates.

FIGS. 9 and 10 also illustrate the operation and purpose of the buffer circuit in accordance with the invention. Whereas the temperatures at the outlet end of the first pass remain relatively close to the temperatures at the outlet end in the second pass, the inlet temperatures into the second pass are in the range of 710° to 730° F., from 25 percent to 100 percent load, while the inlet temperatures into the first pass are in the range of 400° to 610° F. from 25 percent to 100 percent load. The positioning of the buffer circuit panels between panels of the first and second passes in effect halves the temperature differences between adjacent tubes. Although this overcomes the problem of thermal stresses for most of the furnace enclosure, the temperature tube-to-tube differences at the pass inlet ends, even with the use of the buffer circuit are in excess of the design limit of about 100° F. (It is understood that the limit of 100° F. to 125° F. may differ depending upon design considerations). However, this is a very hot area of the furnace

and the temperature increase in the first pass at the inlet end will be very rapid, as shown in FIGS. 9 and 10. Accordingly, tube-to-tube temperature differences greater than the design limit will exist only in the very lower part of the furnace, generally confined to the hopper, but definitely to an area below the burners. Accordingly, it is within the scope of the invention to seal weld the furnace, using the concepts of FIG. 4, only above the hopper, or the elevation at which the tube-to-tube maximum temperature difference drops to less than the design limit. Below this elevation, which usually will be close to the hopper, but between the hopper and the burners, a conventional seal casing construction can be used.

In this respect, the generator is top supported, so that growth in the walls of the furnace enclosure can be in a downward direction.

It has been mentioned that the present invention is for use primarily with oil or gas firing, and the embodiment illustrated and described above is a design especially adapted for this type firing. In particular, the fuel combustion within the furnace is characterized by a high heat release per square foot of surface, and the present invention takes advantage of this fact towards increasing the overall generator rating while maintaining fluid circuit flow stability. It will be recalled that "rating" can be defined as the average number of B.t.u.'s per hour absorbed per square foot of surface area exposed to hot gases.

Towards increasing the average absorption per square foot of surface area, or generator rating, the design of the present invention among other things is one in which the maximum permissible furnace exit gas temperature, for the fuel fired, is used. Because of this design choice, the log-mean temperature difference for heat transfer from the flue gases to the superheater and reheater convection sections is held at highest values to minimize this required surface.

The embodiment in FIG. 1 shows the platen (or pendant) superheater surface 55 and the finishing superheater 30 positioned in a relatively high temperature area of the furnace convection enclosure, so that the highest log-mean temperature difference (between the gases passing over these superheater surfaces and the fluid within the superheaters) can be utilized to minimize surface requirements for these expensive sections.

Also to increase the rating, it is proposed in accordance with the present invention to employ the most densely packed surface arrangement as possible in the heat recovery portion of the generator with a predetermined sized enclosure, and still maintain gas flue velocities within design limits.

In addition, the relatively low cost economizer surface 56, is maximized to achieve the highest fluid enthalpy pickup for the economizer within design limits.

Advantages of the invention should now be apparent. By designing for the maximum permissible furnace exit gas temperature, the furnace enthalpy absorption is reduced to the extent that the furnace periphery, at least in the lower part of the furnace, can be divided into two flow passes in series, the enthalpy pickup per pass being low enough to provide stable circuit characteristics; i.e., sufficiently low to reduce the likelihood of a flow imbalance caused by a heat absorption upset. The use of two passes in series permits positioning the passes in opposed walls of the furnace enclosure, with the cooler tubes of the enclosure facing and adjacent to the burners, and with panels of each pass in similar absorption zones. This pass distribution plus selected tube sizes provides a pass geometry which is relatively insensitive, primarily by virtue of high mass flow rates, to flow imbalance should it occur; i.e., the mass flow rates are sufficient to provide proper cooling of the tubes in the event of a flow imbalance.

It should also be apparent that the present invention provides a more simplified furnace circuitry than heretofore used, requiring fewer welds, downcomers, and piping, and constitutes a particular improvement in avoiding the need for such furnace protecting arrangements as gas recirculation, or fluid recirculation.

Further, the present invention by virtue of higher flue gas exit temperatures, and larger log-mean temperature differences in the convection portion of the generator provides a means by which more vapor can be generated with less surface than in conventional units (that is, by which the generator rating can be increased), capital costs for the generator thereby being reduced.

The embodiment of FIGS. 1-7 described above is for a furnace which would be gas fired a substantial portion of the time, and oil fired perhaps a quarter of the time. It may be desirable to use essentially the same generator design in a totally oil-fired unit, in which case the generator would be rated at a slightly lesser value, with a slightly larger furnace enthalpy pickup (a larger dimensioned furnace).

In this case, the furnace flue gas exit temperature would still be relatively high, limited only by design criteria relating to fuel properties, well above conventional designs, but offering a slightly lower log-mean temperature differences to superheater and reheater surface than in the embodiment described above.

To avoid a flow upset in the larger furnace, particularly in the sidewalls of the furnace, the sidewalls are divided as shown in FIG. 8 into second and third passes (110, 112 respectively), with the third pass occupying the upper portion of each of the sidewalls and the second pass the lower portion. Mix headers 114 illustrated in FIG. 8 are disposed between the second and third passes at an elevation about one-half to two-thirds of the height of the enclosure walls, the passes being terminated and in end-to-end relationship at this elevation. This design modification reduces the enthalpy pickup in any one pass, provides an intermediate mixing location, and minimizes the probability of a flow upset caused by absorption differences in tubes of the passes.

The mix header arrangement forms no part of this invention, and a typical mix header arrangement is illustrated in prior U.S. Pat. No. 3,343,523, assigned to assignee of the present application.

Despite the use of a third pass in the sidewalls of the upper portion of the furnace, the advantages of the invention would still result. Short connections only are required between the second and third passes, avoiding the need for additional downcomers. In addition, the log-mean temperature difference in the convection part of the generator is sufficiently large to increase the rating of the generator. Further, the enthalpy pickup per pass is maintained sufficiently low to achieve stable circuit characteristics, and the pass geometry is such as to render the circuitry relatively insensitive to flow imbalance caused by heat absorption upsets.

A further embodiment in accordance with the invention is illustrated in FIGS. 11 and 12. In this embodiment, a full division wall 120 is provided between the front and rear walls 122 and 124, and parallel with the sidewalls 126 and 128. The division wall has the same height and geometry (tube sizes) as the sidewalls and is connected into the circuitry in parallel with the sidewalls, so that it is part of the furnace second pass, receiving a flow from the outlet end of the first pass front and rear walls via downcomers 130 and 132; the flow from the downcomers passing to both the headers 134 for the division wall and headers 136 for the sidewalls. The advantage of this embodiment is that it provides a means inexpensively to shorten the furnace height for a given fluid enthalpy absorption. For a given burner firing rate the combined side and division wall surfaces of the shorter furnace, plus the front and rear walls, have substantially the same heat absorption as the taller walls of the generator of FIGS. 1-7.

The embodiment of FIGS. 11 and 12 offers substantially all of the advantages in accordance with the invention, primarily a means to obtain, economically, stable circuit characteristics and relative insensitivity to flow imbalance with a minimum number of furnace passes. In addition this embodiment provides a means for increasing the generator rating in accordance with the invention.

If desired, the concepts of FIGS. 11 and 12 can readily be incorporated into the embodiment of FIG. 8.

Although the invention has been described with reference to particular embodiments, variations within the scope of the following claims will be apparent to those skilled in the art.

We claim:

1. A once-through vapor generator comprising:
 - a plurality of parallel vertically oriented tubes defining an upright furnace enclosure including front, rear and sidewall panels;
 - header means dividing said furnace enclosure into first and second flow passes in series flow relationship; and
 - one of said flow passes constituting substantially the full expanses of the front and rear wall panels of the furnace enclosure, the other of said flow passes occupying substantially the full expanses of the sidewall panels of the furnace enclosure.
2. The generator of claim 1 wherein said furnace enclosure comprises an upper gas exit and a lower high-absorption zone; further including:
 - convection surface enclosure means in gas flow communication with said furnace enclosure gas exit;
 - burner means in said lower high-absorption zone;
 - said furnace enclosure panels being limited in dimension so that the gas temperature adjacent said gas exit is substantially the maximum value permissible for the fuel fired.
3. The generator of claim 2 wherein said burner means are positioned in both the front and rear wall panels of said furnace enclosure; said first and second flow passes extending the full height of said furnace enclosure, the first flow pass constituting said front and rear wall panels.
4. The generator of claim 3 wherein said furnace includes an upper zone in addition to said lower high-absorption zone, the tube diameters in said upper zone being greater than the diameters in said lower zone to reduce the pressure drop in said passes, the tube diameters in the lower zone being sufficiently small to maintain mass flow rates in said high-absorption zone at above acceptable minimum levels.
5. The generator of claim 2 wherein said front, rear and sidewall panels are substantially flat defining a rectangular furnace enclosure; further including buffer circuit panels each comprising a plurality of parallel tubes defining upright corners of said furnace enclosure, between said front, rear and sidewall panels; header means arranged to distribute to said buffer circuit panels substantially equal portions of the flow being distributed to said first and second passes, so that the temperatures in said buffer circuit panels are intermediate the temperatures in the panels of said first and second passes.
6. The generator of claim 5 wherein said furnace enclosure is substantially all-welded to provide a gastight membrane wall construction.
7. The generator of claim 2 further including primary and finishing superheater passes, said primary superheater pass including pendant radiant heat transfer surface adjacent the gas exit of said furnace enclosure, said finishing superheater pass comprising heat transfer surface positioned on the convection side of said gas exit, adjacent thereto.
8. The generator of claim 1 further including a third flow pass comprising wall panels in end-to-end relationship with the wall panels of said second flow pass;
 - said third flow pass panels being laterally substantially coextensive with the second flow pass panels but above the latter so that said second and third pass panels together have about the same height as said first pass panels;
 - mix header means between said second and third pass panels;
 - burner means in the lower portion of said furnace enclosure, said burner means being predominantly oil fired;
 - said furnace enclosure defining gas exit means adjacent the top thereof; and
 - the temperature of the flue gas adjacent said gas exit means being the maximum permissible value for the fuel fired.
9. The generator of claim 1 further including downcomer means between said first and second passes;

horizontal exit header means for said first pass panels; said downcomer means comprising a horizontal manifold extension above said furnace enclosure substantially parallel with said header means and downwardly extending side connections connected to said manifold extension on opposite sides of said enclosure;

fan-mix connection means between said header means and said downcomer means horizontal extension; and

said fan-mix connection means comprising connections between said exit header means and said manifold extension which lead from one end of each header means to a corresponding end of the manifold extension and alternately to an opposite end of the extension, connected to the latter near the center of said manifold extension, more centered header connections leading to portions of the manifold extension more removed from the center of the latter.

10. The generator of claim 3 further including a division wall panel, said division wall panel being parallel to the sidewall panels, coextensive in height therewith, and having the same geometry, said header means connecting said division wall panel so that the flow therein is in parallel with the flow in the sidewall panels.

11. A once-through vapor generator comprising:

an upright substantially rectangular furnace enclosure including a plurality of parallel vertically oriented tubes defining front, rear and sidewall panels;

said enclosure comprising a lower high absorption zone and an upper gas exit;

header means connecting said tubes to define first and second flow passes in series, the first flow pass constituting substantially the full periphery of the front and rear wall panels of said enclosure and the second flow pass constituting substantially the full periphery of the sidewall panels of said enclosure, at least in said high-absorption zone;

burner means positioned in the front and rear wall panels in said lower high-absorption zone;

a plurality of parallel upright tubes defining buffer circuit panels positioned in said enclosure between the front, rear and sidewall panels of said first and second passes;

header means for said buffer circuit panels;

connections between said header means and said first and second passes whereby the flow to said buffer circuit panels comprises substantially equal amounts of the flows at fluid conditions existing at the first and second pass inlets; and

said furnace enclosure panels being limited in dimension so that the gas temperature adjacent said gas exit is substantially the maximum value permissible for the fuel fired.

12. The generator of claim 11 wherein said furnace enclosure includes an upper gas exit zone in addition to said lower high-absorption zone; the tube diameters of said first and second passes being increased in said upper gas exit zone reducing the pressure drop therein, but maintaining minimum required mass flow rates in said lower high-absorption zone.

13. The generator of claim 12 wherein said furnace enclosure is all-welded to provide a membrane wall-type construction.

14. A once-through vapor generator comprising:

a plurality of parallel vertically oriented tubes defining an upright furnace enclosure including front, rear and sidewall panels;

header means dividing said furnace enclosure into first and second flow passes in series flow relationship; and

one of said flow passes constituting substantially the full expanses widthwise of the front and rear wall panels of the furnace enclosure, the other of said flow passes occupy substantially the full expanses widthwise of the sidewall panels of the furnace enclosure, said passes constituting a substantial portion of the furnace enclosure.