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ONCE-THROUGH STEAM GENERATOR HAVING A CENTRAL MANIFOLD
AND TUBE BUNDLES OF SPIRAL TUBE CONSTRUCTION

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2 Sheets-Sheet 1

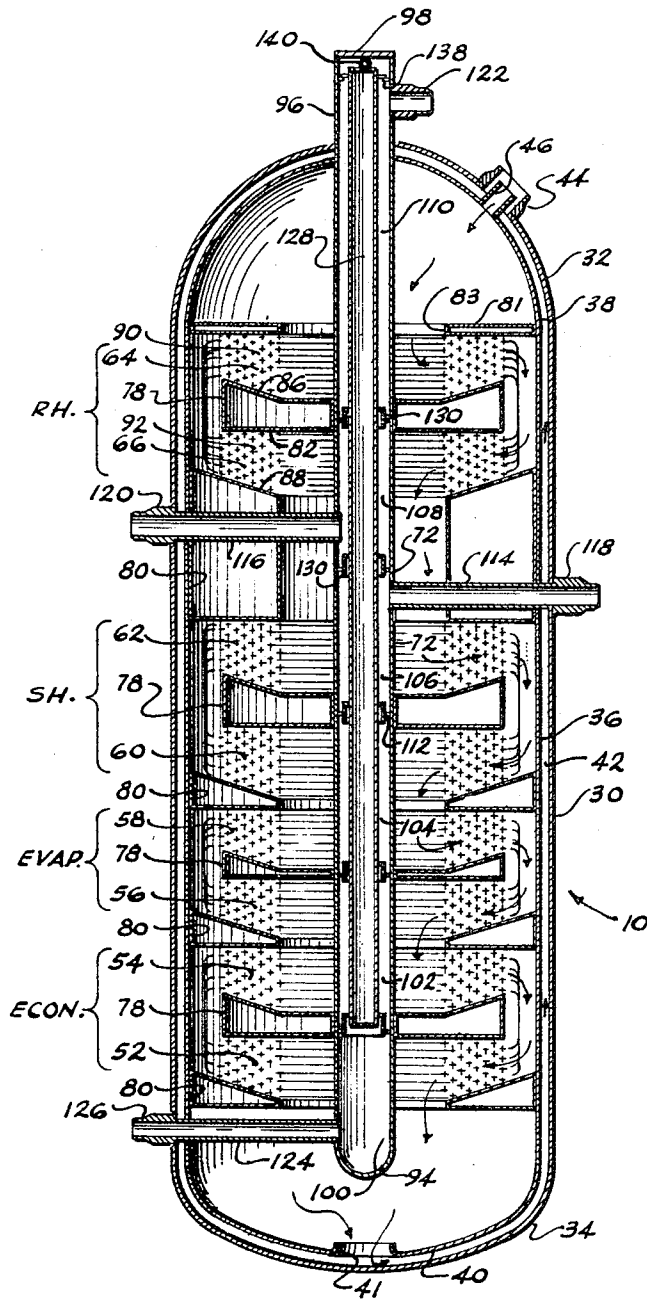


FIG-2

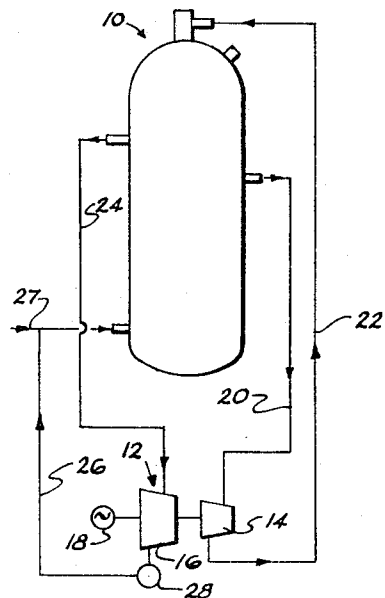


FIG-1

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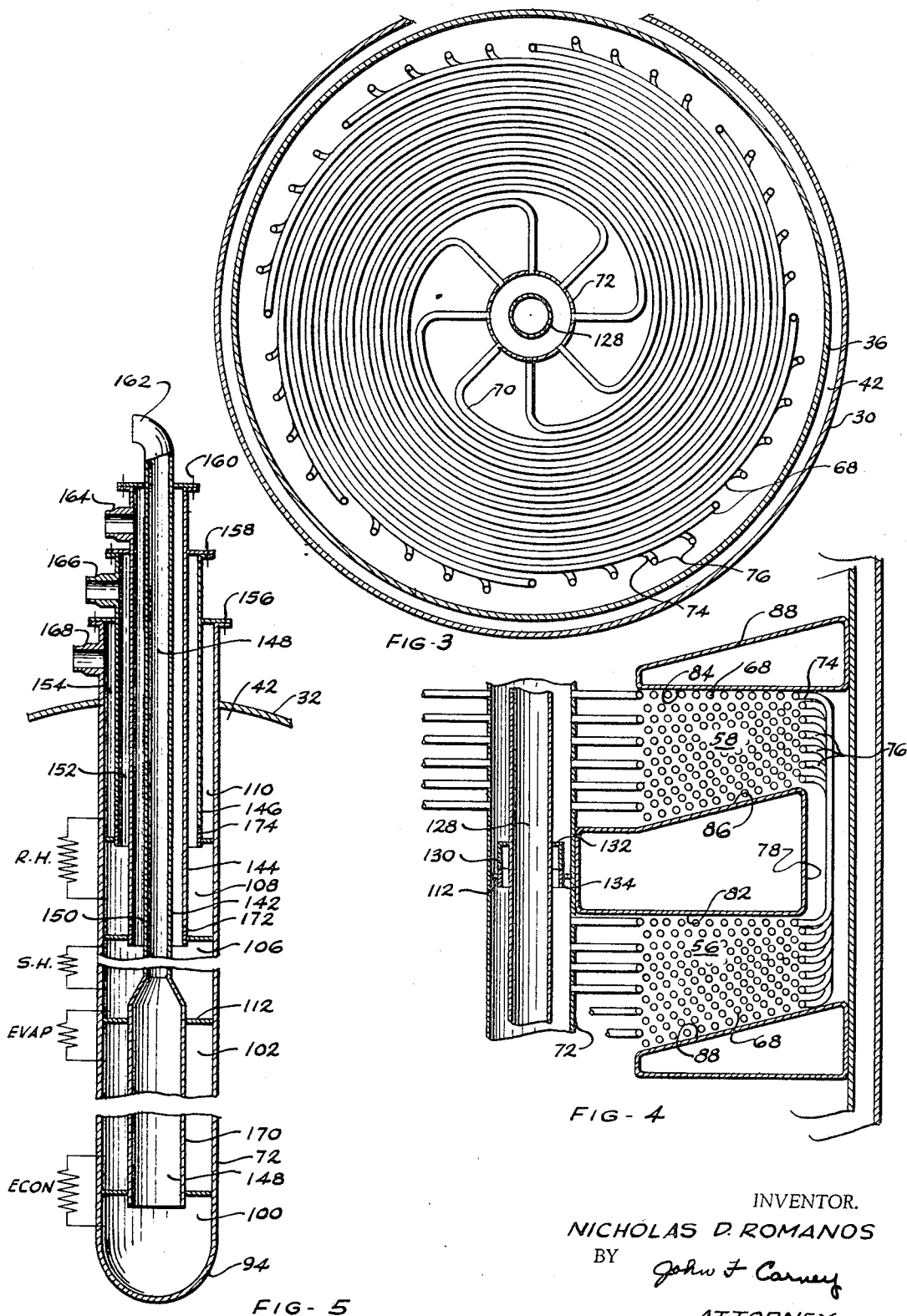
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ABSTRACT OF THE DISCLOSURE

A once-through, gas-operated vapor generator of shell and tube design wherein a number of tube bundles representing the economizer, evaporator, superheater and reheater sections of the unit are arranged for series flow of vaporizable fluid. Each of the tube bundles comprises a group of spirally wound heat exchange tubes arranged in vertically spaced layers. The tube bundles are connected for series flow by an axially extended manifold conduit to which the tubes communicate. The conduit is appropriately partitioned into axially spaced chambers so as to define, in conjunction with the tube bundles, a continuous vaporizable fluid flow path through the unit.

This invention relates to heat exchangers of the type comprising a shell providing a flow path for heating fluid and containing a bank of tubes for the passage of a vaporizable fluid.

In the known use of such a heat exchanger as a boiler for vapor generation, a gas heated in passage through a heat source, such as a chemical process reactor or the like, is passed through the shell of the heat exchanger, the liquid and vapor consequently generated being passed through the tubes. Heat exchangers of this type of heretofore known design commonly encounter several manifest disadvantages. Firstly, in the design of such units it is desirable to provide the greatest amount of heat exchange surface within a shell consistent with acceptable unit efficiency. This, however, results in crowded conditions within the shell that hinders or prevents service or maintenance of the tubes without physically removing the tube bank from the shell and/or dismantling the tubes from the tube bank. Another disadvantage encountered by such units is the fact that much of the heat carried by the gases flowing through the shell is lost to the exterior thereof thus resulting in stratification of gas temperatures with the gases flowing through the center of the unit being considerably hotter than those that flow adjacent the shell wall. Such stratification results in non-uniform heating of the tubes and a reduction in vapor generator efficiency caused by the heat lost to the exterior of the shell. Heat exchangers of the instant type suffer from a further disadvantage in that they are not conveniently adaptable for use in a reheat vapor cycle which is known to be of greater thermal efficiency than other conventional power plant cycles. Units of heretofore known design, while being capable of generating vapor at superheat temperatures, have, of necessity, been prevented from use in reheat vapor cycles without the use of separate or independent vapor reheat apparatus which, of course, greatly increased the fabrication and piping costs of the system.

By means of the present invention there is provided a heat exchanger of the shell and tube type adapted for operation as a vapor generator in a power plant cycle without the disadvantages of heat exchangers of known construction. The instant arrangement involves a heat exchanger capable of generating vapor at superheated temperatures and possessing an integral vapor reheater adapting the unit for use in a reheat vapor cycle. The novel con-

struction employs a tube bank comprising a plurality of serially connected tube groups defining the fluid heating, superheating and reheating sections of the unit. Each tube group is similarly constructed of a plurality of layers of spirally wound heat exchange tubes whose ends are connected to an axially elongated manifold conduit that is coextensive with the tube bank and which connects each of the vapor generator sections for series flow of fluid. The manifold conduit contains compartment-forming partition means that can be readily dismantled and removed from the conduit, thereby exposing the ends of all of the tubes for service by a workman or by remotely operated tool means.

In the present arrangement, means are also provided to prevent stratification of the gases flowing through the shell and thereby providing a uniform transfer of heat from the gases to the fluid flowing through the tubes of each tube group. Such means includes a system of baffles that forms a tortuous gas flow path through the tube bank wherein the gases are caused to flow alternately inwardly and outwardly through the spaces that house each of the tube groups, thereby resulting in a more uniform transfer of heat throughout the entire transverse section of the unit.

For a better understanding of the invention, its operating advantages and the specific objects obtained by its use, reference should be made to the accompanying drawings and description which relate to various embodiments of the invention. In the drawings:

FIGURE 1 is a schematic representation of a power plant utilizing the novel vapor generator of the present invention;

FIGURE 2 is a vertical section of the vapor generator according to a preferred embodiment of the invention;

FIGURE 3 is a section taken along line 3—3 of FIGURE 1;

FIGURE 4 is an enlarged partial section through a typical pair of tube groups; and

FIGURE 5 is a partial vertical section of a modified embodiment of the present invention.

Referring now to FIGURE 1 of the drawings, there is shown a schematic representation of a power plant operating on a vapor reheat cycle and including a vapor generator 10 according to the present invention. The power plant also comprises a turbine 12 having high and low pressure stages 14 and 16, respectively, and an electric generator 18 operatively connected thereto. Connecting the stages of the turbine 12 to the vapor generator 10 are lines 20, 22, 24 and 26, the latter of which includes a vapor condenser 28 on the discharge side of the low pressure stage 16 of the turbine. The vapor generator 10 employs gas as its heating medium, which may be the primary coolant of a chemical process reactor (not shown), or the like. As is conventional in such power plants, superheated vapor produced by the vapor generator 10 is passed to the high pressure stage 14 of turbine 12 through line 20. After passing through stage 14 the spent vapor at a reduced pressure is returned to the vapor generator 10 through line 22 for reheating and is thereafter passed to the low pressure stage 16 through line 24. The fluid discharge from the low pressure stage 16 is condensed in condenser 28 and then passed through line 26 together with makeup liquid which enters through line 27 to the vapor generator 10 for recycling therethrough.

As shown in FIGURE 2, the vapor generator 10 of the present invention comprises a vertically elongated, cylindrical pressure vessel 30 having a hemispherical upper end cap and an ellipsoidal lower end cap 34. A cylindrical shell 36 having a domed upper end 38 and a dished lower end 40 is coaxially suspended within the vessel by means of brackets (not shown). The shell 36 is disposed in

spaced relation from the wall of the vessel 30 and defines an annular passage 42 therebetween which communicates with the interior of the shell by means of an opening 41 in the lower end 40 thereof. Concentrically related nozzles 44 and 46 are attached to and penetrate the upper end cap 32 of the vessel and upper end 38 of the shell respectively, to form a gas inlet communicating with the interior of the shell as a gas outlet communicating with the annular passage 42 for circulating gaseous heating fluid between the vapor generator 10 and a heat source (not shown).

An axially elongated tube bank for conducting vaporizable fluid through the unit is provided within the interior of the shell 36. The tube bank comprises a number of series-connected, axially spaced tube groups 52, 54, 56, 58, 60, 62, 64 and 66 which together define the economizer, evaporator, superheater and reheater sections of the vapor generator 10. Each of the tube groups, 54 through 66, is of generally annular configuration and consisting of layers of spirally wound heat exchange tubes 68. As shown in FIGURES 3 and 4 the tubes 68 in each layer have inner ends 70 that are generally straight and radially connected to a manifold conduit 72 about the circumference thereof. The remaining portion of the tubes 68 is spirally wound about the axis of the shell with their outer ends 74 terminating in connectors 76 that unite adjacent pairs of tube groups to define each of the vapor generator sections.

The flow path transversely by the heating fluid in flowing from the gas inlet 48 through the tube bank is defined by plate means forming axially spaced, generally cylindrical baffles 78 and 80 which direct the heating fluid tortuously through the shell 36. As shown, the baffles 78 and 80 are alternately disposed between adjacent tube groups with the baffles 78 having their inner peripheral edge secured to the conduit 72 and their outer edge spaced from the wall of the shell 36. The baffles 80, on the other hand, have their outer peripheral edge secured to the wall of the shell 36 and their inner edges spaced from the conduit 72. Thus the baffles 78 and 80 cooperate to direct the gaseous heating fluid alternately inwardly and outwardly through the spaces occupied by the tube groups such that temperature stratification of the heating fluid is prevented. The upper end of the tube bank may be covered by an annular baffle 81 having a central opening 83 through which gases entering the tube bank from the gas inlet 48 are permitted to pass.

Each of the baffles 78 and 80 are constructed with a substantially horizontal lower surface 82 and 84, respectively. The upper surfaces, 86 and 88, of these baffles are conically recessed such that the opposing surfaces, 82 and 86, and 84 and 88, of adjacent baffles form alternately convergent and divergent passages 90 and 92 through which the gas flows in passing through each of the tube groups. The slope of the conical surfaces 86 and 88 is such as to compensate for the change in gas flow area dimensions of the shell interior encountered by the heating fluid in flowing in the radial direction. In this manner the heating fluid flow area is maintained substantially constant along the flow path through the shell such that the velocity of the fluid flowing therethrough is concomitantly rendered uniform.

The manifold conduit 72 which connects the inner ends of the tubes is an axially elongated cylindrical member extending concentrically through the vessel 30 and shell 36. The lower end of the conduit 72 is spaced from the lower end 40 of the shell and is closed by means of an end cap 94. The upper end of the conduit 72 penetrates and is attached to both the upper end cap 32 of vessel 30 and the upper end 38 of shell 36. An extension 96 of conduit 72 extends vertically beyond the end cap 32 and has an open upper end that is closed by a threadedly attached removable closure 98. The interior of the manifold conduit 72 is divided into axially spaced compartments 100, 102, 104, 106, 108 and 110 which serve, together with the tube connectors 76, to unite the tube

groups for series fluid flow. The compartments 100 through 110 are formed by horizontally disposed annular divider plates 112 having their outer edges secured to the inner surface of the manifold conduit 72 at axially spaced points therealong. As shown, the divider plates 112 are located within the conduit between the connections of the tube ends of the alternate tube groups. Thus, the compartment 100 forms the feedwater inlet compartment; compartment 102, the connection between the economizer section and the evaporator section; compartment 104, the connection between the evaporator section and the superheater section; compartment 106 is the superheater outlet compartment; compartment 108, the reheater outlet compartment; and compartment 110, the reheater inlet compartment. Radially extending ducts 114 and 116 connect between the conduit 72 and the vessel 30 communicating with compartments 106 and 108, respectively, to form the superheater and reheater outlets. Nozzles 118 and 120 are attached to the wall of the vessel 30 for connecting the ducts 114 and 116 to appropriate vapor lines indicated as lines 20 and 24 in FIGURE 1. Nozzle 122 is attached to the conduit extension 96 and establishes fluid communication between line 22 and compartment 110 for returning vapor to the unit for reheating. Feedwater liquid is supplied to the compartment 110 through a feedwater duct 124 that extends between the vessel 30 and the manifold conduit 72. A nozzle 126 attaches the outer end of the duct 124 to a source of liquid.

A manifold conduit plug 128 which may be in the form of a rigid rod or cylinder having closed ends, extends axially into the conduit 72 and is substantially co-extensive therewith. The upper end of the plug 128 is provided with an annular flange 136 adapted to be removably attached as by means of threaded connectors to a cooperating flange 138 on the inner surface of conduit extension 96 adjacent the upper end thereof. A lifting lug 140, or the like, may be attached to the upper end of plug 128 for connection to a lifting mechanism capable of removing the plug from the conduit. Attached to the plug 128 in cooperating relation with the divider plates 112 are a plurality of seal skirts 130. The seal skirts 130 are provided at their upper ends with an attaching flange 132 for securing the skirts to the plug. Their lower ends are open and free to expand into sealing engagement with the inner edge of the divider plates 112 formed by openings therein that are of a size to receive the plug and skirts. As shown in FIGURE 4, the lower end 134 of the skirt 130 is formed of a material having a higher coefficient of thermal expansion than that of the divider plates 112 and conduit 72 such that when subjected to elevated temperatures as when the unit is operating at relative expansion between the lower ends 134 of the skirt 130 and the inner edge of the divider plates 112 will effect a fluid seal therebetween to effectively render the adjacent compartments fluidly distinct. In the alternative, the entire seal skirt, rather than merely the lower end 134, may be formed of a material having a higher coefficient of thermal expansion than the remaining structure.

The operation of the vapor generator is as follows. The conduit plug 128 is inserted in place within the manifold conduit 72 with the flange 136 threadedly secured to the shoulder 138 and the lower ends 134 of the seal skirt 130 loosely received in the openings provided between divider plates 112. Conduit cover 98 may be threadedly secured in place and thereafter gaseous heating fluid is admitted to the shell 36 through inlet 48 from whence it flows along a tortuous path through the tube bank leaving the bottom of the shell through opening 41 in the lower end 40 thereof. The heating fluid then flows along passage 42 and leaves the unit through the outlet 50 to be recycled through its source. As the temperature within the vapor generator 10 increases the ends 134 of the seal skirt 130 are expanded radially into engagement with the inner edges of the divider plates 112, thereby sealing the compartments 100 through 110

from one another to effectively connect each of the tube groups for series flow. Meanwhile vaporizable liquid is admitted to the unit through nozzle 126 and duct 124 from whence it flows seriatim through the compartments 100 through 106 and tube groups 52 through 62 leaving the unit as superheated vapor through the outlet ducts 114 and nozzle 118. From the nozzle 118 the vapor is passed through line 120 to the high pressure stage of turbine 12 where its pressure is expended in driving the turbine. The vapor is discharged at a lower pressure into line 22 which returns it to the vapor generator through the reheater inlet nozzle 122 in compartment 110 from whence it flows through tube groups 64 and 66 in heat exchange relation with the gas in that area of the shell 36 whereby the vapor is superheated to a higher temperature. The reheated vapor is discharged from the tubes 68 of tube group 66 into compartment 108 from whence it flows through duct 116, nozzle 120 and line 124 to the low pressure turbine stage. The spent vapor is discharged from the low pressure stage 16 into condenser 28 and the liquid returned to the vapor generator 10 through line 26 together with makeup liquid that may be added through line 27 for recycling.

When it is desired to perform maintenance service on the vapor generator, the flow of gases and liquid to the unit is terminated and the vessel 30 and shell 36 permitted to cool. At the lower temperatures, the relative thermal expansion between the ends 134 of the seal skirt 130 and the divider plates 112 is such that the seals between the members are broken and the plug 128 free to be withdrawn from the manifold conduit 72 once the threaded connection between flanges 136 and 138 is loosed. Lifting mechanism is attached to the lifting lug 140 atop the plug 128 to remove the latter from the unit, thus leaving the interior of the conduit unobstructed for entry by a workman or remote control tools for access to all the ends 68 connected to the conduit.

FIGURE 5 illustrates a slightly modified embodiment of the invention wherein the vessel and shell penetrations required to accommodate the vaporizable liquid inlet duct 124, the superheater outlet duct 114 and the reheater outlet duct 116 in the FIGURE 2 arrangement are eliminated. In this embodiment the structure of vessel 30, shell 38, the tube bank and manifold conduit 72 remains the same as in the earlier arrangement. The conduit plug 128 and seal skirts 130, however, are replaced by an assemblage of concentrically spaced tubes 142, 144 and 146 that are disposed within the manifold conduit 72 and cooperate therewith to form concentric fluid flow passages 148, 150, 152 and 154. The tubes and manifold conduit are detachably secured in assembled relation by means of flanged connections 156, 158 and 160 that are adapted to accommodate threaded connectors, or the like. Nozzles 162, 164, 166 and 168 are attached to the respective tubes and manifold conduit adjacent the outer end thereof for connecting the fluid flow passages and compartments into the power plant flow system. As shown the lengths of the three tubes 142, 144 and 146 are such that the passages 148, 150, 152 and 154 formed thereby are each caused to communicate with one of the compartments 100, 106, 108 and 110. The innermost tube 142 may be provided with an enlarged extension 170 for the purpose of reducing the available fluid flow area within compartment 102 such that the velocity of the fluid flowing through the compartment is not inordinately reduced. Therefore, by means of the arrangement, the passage 148 establishes fluid communication between the feed liquid inlet nozzle 162 and compartment 100; passage 150 connects the superheater outlet nozzle 164 and compartment 106; passage 152 connects the reheater inlet nozzle 166 and compartment 108; and passage 154 connects the reheater outlet nozzle 168 and compartment 110.

As in the FIGURE 2 embodiment of the invention the compartments 100, 102, 104, 106, 108 and 110 pro-

vided in the manifold conduit 72 are separated, one from the other, by horizontally disposed divider plates 112 having central openings of a size adapted to permit free passage of the tubes 144 and 146 and tubular extension 170 of tube 142. Instead of the provision of seal skirts 130 as in the earlier arrangement, the fluid seal provided between the compartments is effected by means of the radial thermal expansion of the lower ends of the tubes 144 and 146 and extension 170. For this purpose all, or preferably only the lower ends, of the tubes 144 and 146, as indicated by numerals 172 and 174 and the extension 170 are formed of a material having a greater coefficient of thermal expansion than the conduit 72 such that when subjected to elevated temperatures as when the unit is placed in operation the expansion of the ends of the tubes 144 and 146 and extension relative to the inner edge of the divider plates 112 will effect a fluid seal to effectively separate the compartments. Thus, easy access to the interior of the conduit 72 and the ends of the tubes 68 for maintenance purposes is effected by the automatic disconnection of the fluid seals upon discontinued operation of the unit and detachment of the flange connection 156 to render the assemblage free to be withdrawn from the conduit.

The description of the invention set forth herein is intended to be merely illustrative and is not intended as a limitation thereof, it being understood that many and varied modifications of the invention can be made without departing from the spirit of the appended claims.

What is claimed is:

1. A vapor generator comprising:

- (a) an elongated shell;
- (b) means for circulating heating fluid through said shell;
- (c) means within said shell defining a heating fluid flow path;
- (d) a bank of tubes arranged in axially spaced groups in said flow path for the passage of vaporizable fluid in indirect heat exchange relation with said heating fluid;
- (e) means for connecting said groups of tubes for series fluid flow including:

- (i) a manifold conduit axially disposed within said shell and substantially coextensive with said tube bank;
- (ii) means dividing said manifold conduit into axially spaced compartments;
- (iii) means connecting one end of the tubes of each tube group to said manifold conduit in communication with one of said compartments;
- (iv) means connecting the other end of the tubes of each tube group with the tubes of an adjacent tube group;

- (f) means for supplying vaporizable liquid to the lowest temperature compartment in said series;
- (g) and means for extracting vapor from a higher temperature compartment in said series.

2. Vapor generator apparatus as recited in claim 1 wherein said tube groups each comprise spaced layers of parallelly disposed, spirally wound heat exchange tubes.

3. Vapor generator apparatus as recited in claim 2 wherein the inner ends of the tubes in each of said tube layers attach radially to said manifold conduit at circumferentially spaced points thereby forming annular tube groups.

4. Vapor generator apparatus as recited in claim 3 including annular baffle means disposed between adjacent tube groups comprising:

- (a) first baffle means having its inner periphery attached to said manifold conduit and its outer periphery spaced from the wall of said shell;
- (b) second baffle means having its outer periphery attached to the wall of said shell and its inner periphery spaced from said manifold conduit;
- (c) said first and second baffle means being alternately

disposed between adjacent tube groups whereby heating fluid is caused to flow alternately inwardly and outwardly through the spaces occupied by said tube groups.

5. Vapor generator apparatus as recited in claim 4 wherein said first and second baffle means have opposed surfaces defining alternate radially convergent and divergent passages to and from said tube group spaces whereby the heating fluid flow area is maintained substantially constant through said tube bank.

6. Vapor generator apparatus as recited in claim 4 including:

- (a) wall means spaced from the wall of said shell and forming an exterior gas flow passage therearound;
- (b) heating fluid inlet means communicating with one end of said shell and heating fluid outlet means communicating with said passage at the end adjacent said inlet means;
- (c) and pump means disposed at the other end of said shell for withdrawing heating fluid therefrom and for passing it to said passage.

7. Vapor generator apparatus as recited in claim 1 wherein said conduit dividing means comprises:

- (a) an elongated plug concentrically spaced from the wall of said conduit and being substantially coextensive therewith;
- (b) cylindrical skirt means concentrically disposed between said plug and conduit;
- (c) means for attaching one end of said skirt to one of said members;
- (d) and means for expanding the other end of said skirt into sealing engagement with the other of said members.

8. Vapor generator apparatus as recited in claim 7 wherein said skirt means is formed of a material having a coefficient of thermal expansion greater than that of said members whereby said skirt means is expanded into sealing engagement upon the application of heat thereto.

9. Vapor generator apparatus as recited in claim 8 wherein said skirt means has its upper end attached to said plug and its lower end expandable into sealing engagement with the wall of said conduit.

10. Vapor generator apparatus comprising:

- (a) an elongated shell;
- (b) means for circulating heating fluid through said shell;
- (c) means within said shell defining a heating fluid flow path;
- (d) a bank of tubes arranged in axially spaced groups, each of said groups forming the economizer, evaporator, superheater and reheater sections respectively of said apparatus;
- (e) means for connecting said sections for series fluid flow including:
 - (i) a manifold conduit axially disposed within said shell substantially coextensive with said tube bank,
 - (ii) partition means dividing said manifold conduit into axially spaced compartments,
 - (iii) the tubes of each of said economizer, evaporator and superheater sections being mutually interconnected and attached to said manifold conduit in communication with the respective compartments therein for series flow of fluid through said tube bank,
- (f) means for withdrawing superheated vapor from the compartment connecting the outlet ends of the tubes of said superheater section;
- (g) means communicating with the compartment connecting the inlet ends of the tubes of said reheater section for supplying spent superheated vapor thereto;
- (h) and means for withdrawing reheated vapor from the compartment connecting the outlet ends of the tubes of said reheater section.

11. Vapor generator apparatus as recited in claim 20 wherein each of said sections comprise spaced layers of parallelly disposed, spirally wound heat exchange tubes having their inner ends attached to said manifold conduit in fluid communication with an associated compartment and their outer ends in series connection with corresponding tubes in an adjacent section for series flow of fluid through said sections.

12. Vapor generator apparatus as recited in claim 11 wherein said partition means comprises:

- (a) an elongated plug concentrically spaced from the wall of said manifold conduit and being substantially coextensive therewith;
- (b) a plurality of axially spaced cylindrical skirts concentrically disposed between said plug and said conduit and each having one end thereof attached to said plug and the other end expandable into sealing engagement with the wall of said conduit.

13. Vapor generator apparatus as recited in claim 12 wherein said elongated plug is axially removable from said conduit.

14. Vapor generator apparatus as recited in claim 11 including means for maintaining a substantially uniform flow of heating fluid through said shell comprising:

- (a) first axially spaced annular baffle means disposed between adjacent tube groups and having its inner periphery attached to said manifold conduit and its outer periphery spaced from the wall of said shell;
- (b) second axially spaced annular baffle means disposed between adjacent tube groups in alternate relation to said first baffle means, said second baffle means having its outer periphery attached to the wall of said shell and its inner periphery spaced from said manifold conduit;
- (c) said first and second baffle means having cooperating surfaces defining inwardly divergent heating fluid flow passages opening into the spaces occupied by each of said tube groups.

15. Vapor generator apparatus as recited in claim 11 wherein said manifold conduit includes:

- (a) means closing the lower end of said conduit;
- (b) tubular means concentrically spaced within said manifold conduit and cooperating to form concentric fluid passages, each communicating with one of said economizer, superheater and reheater sections;
- (c) and nozzle means connecting each of said fluid passages with the exterior of said shell.

16. Vapor generator apparatus as recited in claim 15 including:

- (a) first, second and third tubular means concentrically spaced within said manifold conduit and cooperating to form concentric fluid passages;
- (b) said first tubular means extending to and communicating with the compartment forming the economizer inlet for supplying vaporizable liquid thereto;
- (c) said second tubular means extending to and communicating with the compartment forming the superheater outlet for removing superheated vapor therefrom;
- (d) said third tubular means extending to and communicating with the compartment forming the reheater inlet for returning spent superheated vapor to the tubes of said reheater section;
- (e) said third tubular means cooperating with the wall of said conduit and forming a reheater outlet passage for returning reheated vapor to its point of use.

17. Vapor generator apparatus as recited in claim 16 wherein said partition means extend between the wall of said conduit and said tubular means to divide said conduit into fluidly distinct compartments communicating with the inlet and outlet ends of the tubes of each of said sections respectively; and wherein at least a portion of said tubular means are formed of a material having a higher coefficient of thermal expansion than that of said manifold conduit whereby a liquid seal is effected between com-

partments by the radial expansion of said tubular means upon the application of heat thereto.

18. Vapor generator apparatus as recited in claim 17 wherein said partition means comprise axially spaced partition plates attached to the wall of said manifold conduit normal to the axis thereof intermediate the inlet and outlet openings of the tubes of each of said sections; and including

(a) a central opening in each of said partition plates for receiving said tubular means;

(b) at least that portion of said tubular means received by said partition plate openings being formed of a material having a higher coefficient of thermal expansion than that of said manifold conduit whereby the outer surface of said tubular means are radially

expanded into sealing engagement with said partition plates upon the application of heat.

19. Vapor generator apparatus as recited in claim 18 wherein said tubular means are axially removable from said manifold conduit.

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