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Petrek

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[54] **LIQUID METAL OPERATED HEAT EXCHANGER**

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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission,** Washington, D.C.

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[52] **U.S. Cl.** **165/142,** 122/32, 122/34, 165/158, 165/135

[51] **Int. Cl.** **F28d 7/12,** F28f 9/02

[58] **Field of Search** 122/32, 34; 165/142, 3, 165/158, 161, 164

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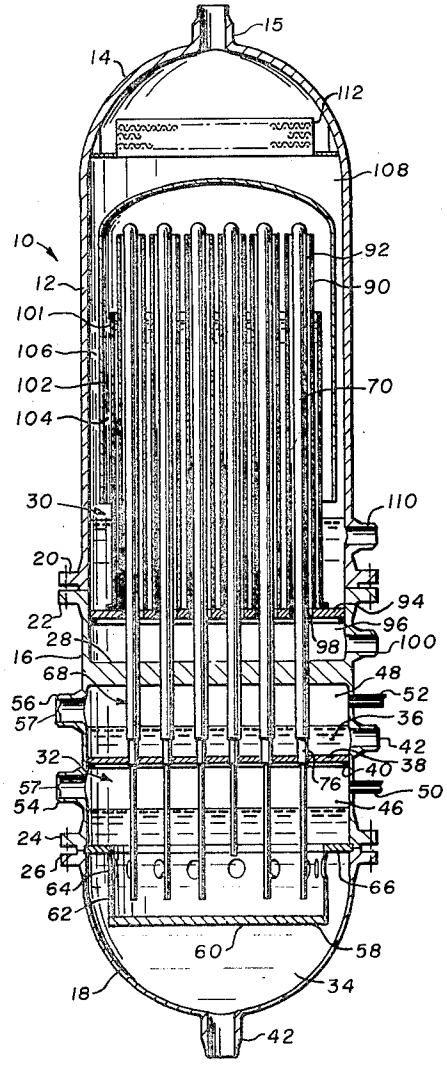
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Assistant Examiner—Theophil W. Streule, Jr.
Attorney, Agent, or Firm—John A. Horan; Dean E. Carlson

[57] **ABSTRACT**

This invention relates to a heat exchanger arrangement of the shell and tube type especially adapted for the use of high temperature liquid metal as a heating medium. The arrangement incorporates a tube bundle comprising a plurality of bayonet tube assemblies through which the liquid metal is circulated in indirect heat exchange relation with vaporizable fluid that flows through the shell. The tube assemblies incorporate a double walled bayonet tube containing a gas space which provides a thermal barrier to minimize heat loss from the heating medium. Various embodiments of evaporator and evaporator-superheater organizations utilizing the heat exchanger arrangement are described.

13 Claims, 4 Drawing Figures



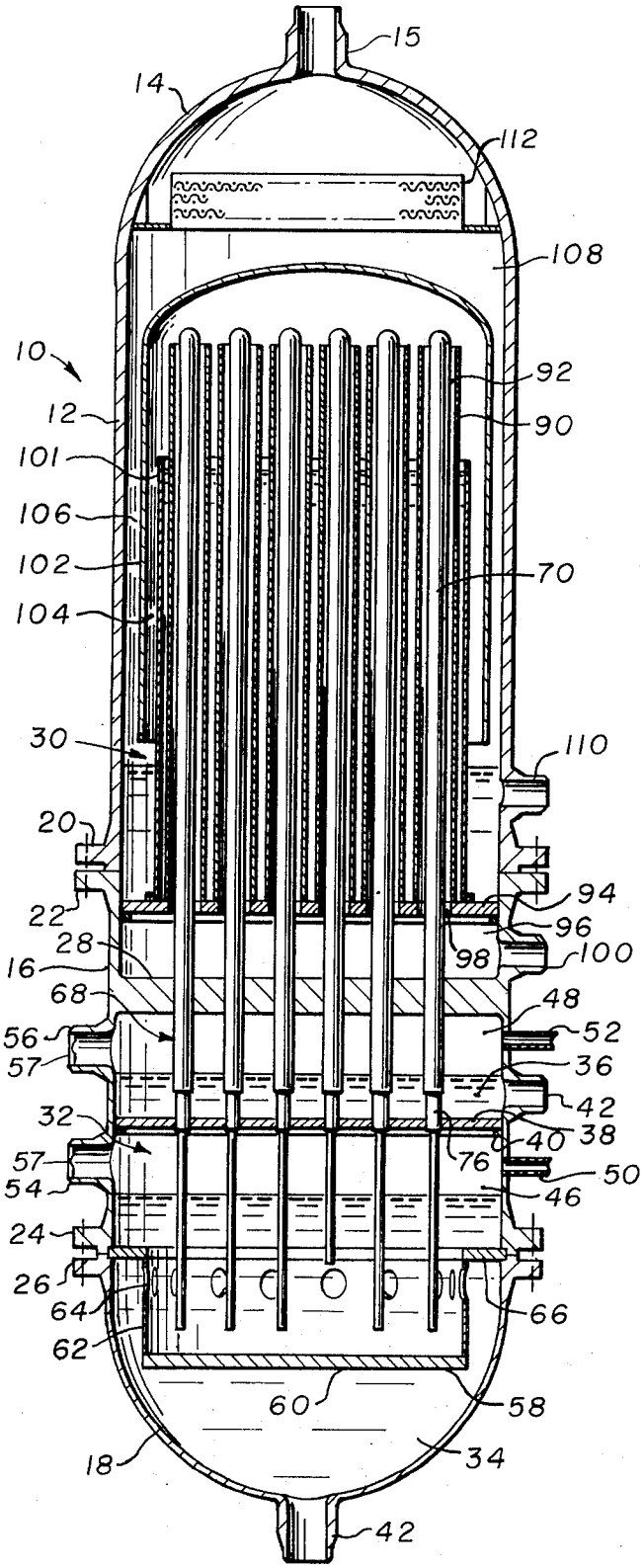

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FIG. 1

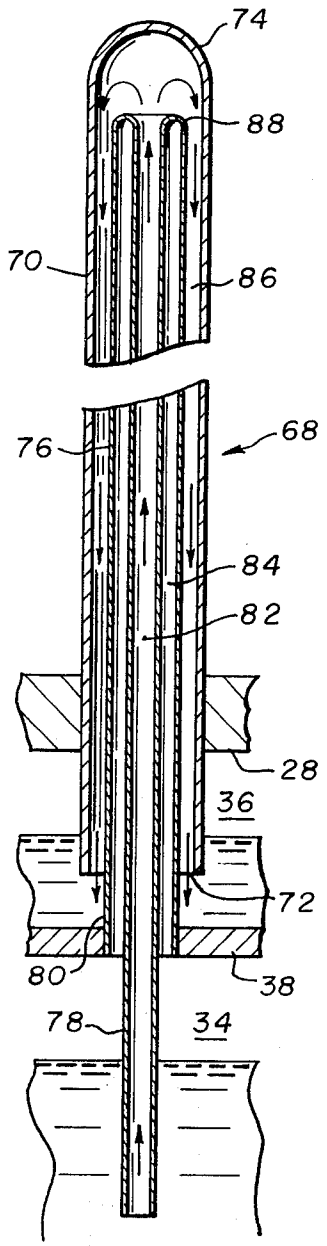

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FIG. 2

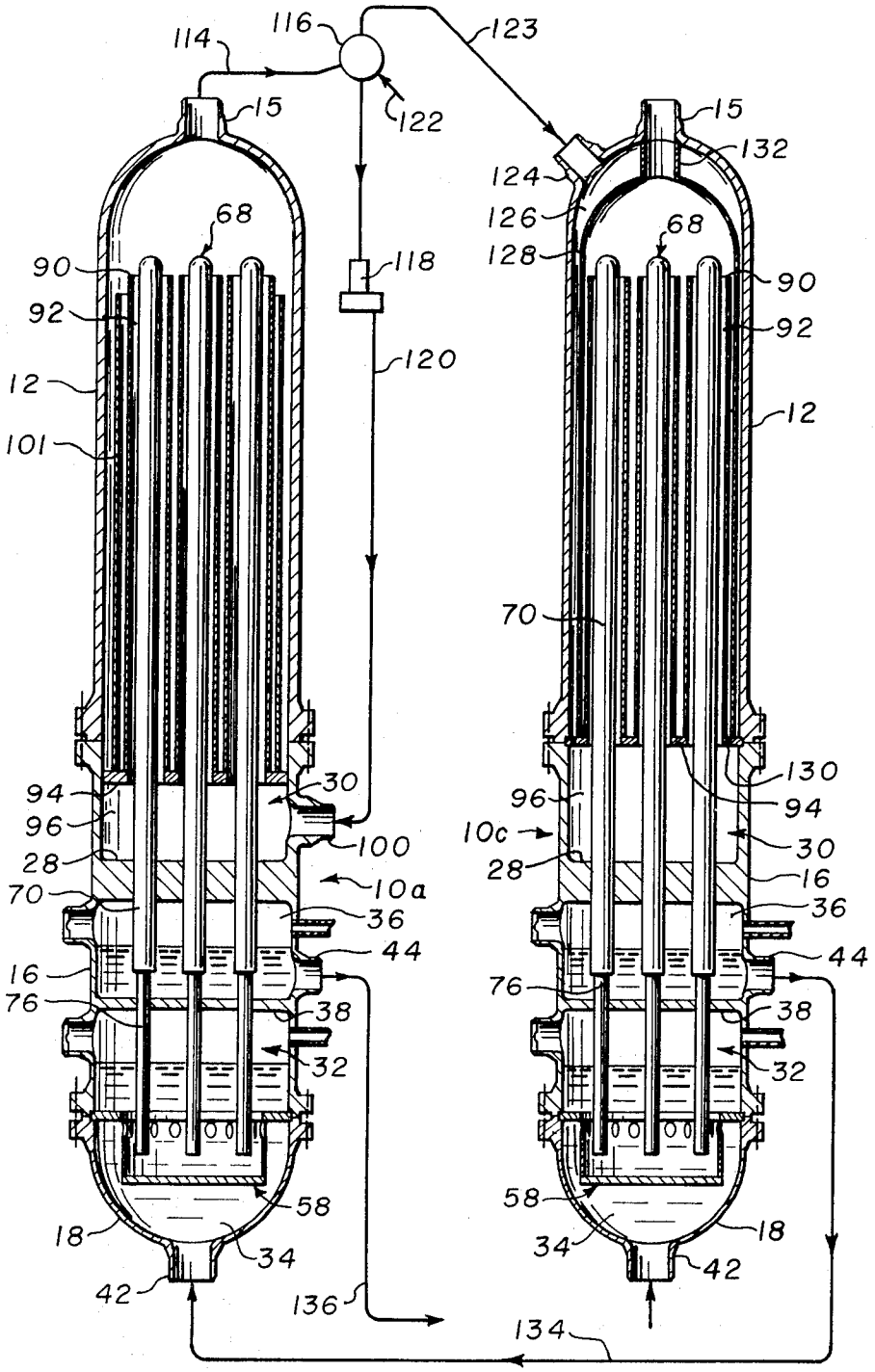

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FIG. 3

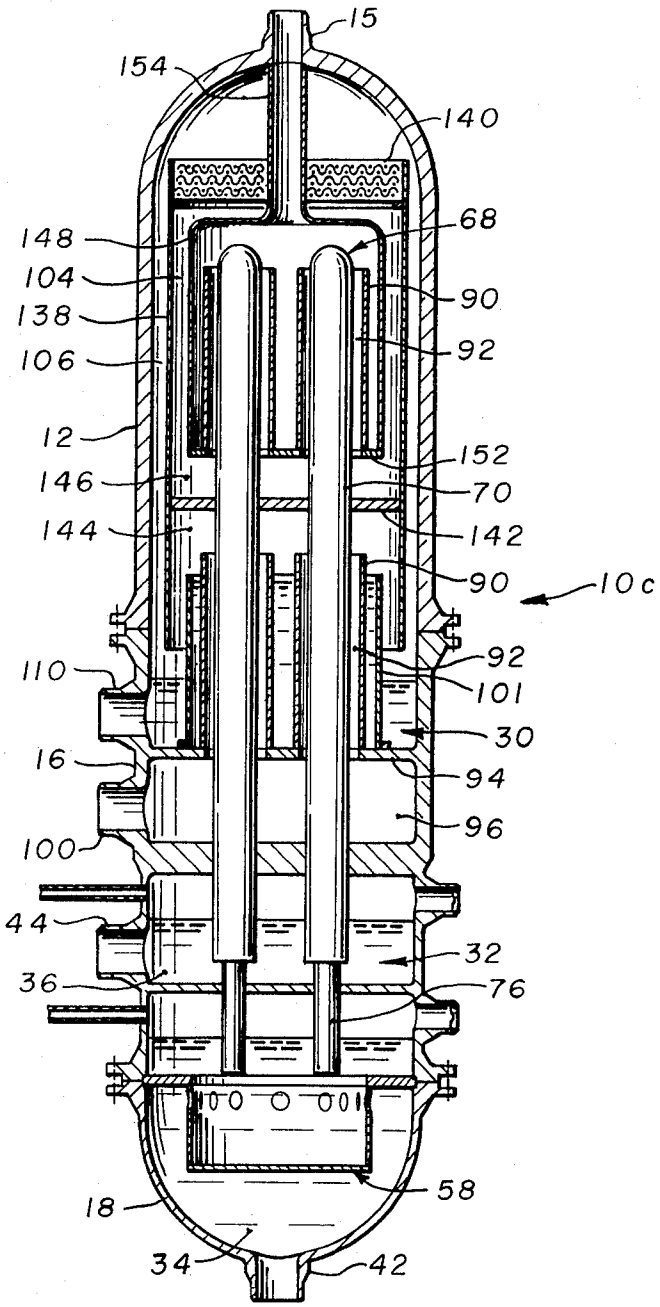

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FIG. 4

LIQUID METAL OPERATED HEAT EXCHANGER

BACKGROUND OF THE INVENTION

Of primary importance in liquid metal operated power plants are the heat exchangers within which heating of the vaporization medium occurs. This component of the plant not only transfers thermal energy from the heating medium to the vaporizable fluid to produce high pressure, high temperature vapor but, where sodium is employed as the heating medium, it must also function to provide an interface between two fluids that are highly chemically reactive. Because of the chemical affinity between sodium and water heat exchangers employed in these organizations are, of necessity, required to have extreme structural integrity. In the past design of these apparatus have been dictated by a balance between considerations of heat transfer efficiency and prescribed safety and reliability considerations. Accordingly, prior art heat exchangers have customarily been of the shell and tube type in which the vaporizable fluid to be heated is circulated through the tubes which are, themselves, immersed in a body of liquid metal that occupies the shell interior.

While apparatus of this type have performed adequately, they nonethless manifest certain undesirable characteristics. Firstly, they require a large sodium inventory. In addition to the increased cost of the material itself and of the equipment required in the heat transfer loop to handle it, the large amount of sodium is detrimental to desirable plant operation in that it retards response to operational changes in the system as dictated by plant controls. Another problem resulting from the large amount of sodium used in these units is the inability of the system to rapidly vent the reaction products produced by the reaction between sodium and water in the event of tube failure thereby requiring the shell to be designed to withstand greater resultant pressure forces.

In addition, other problems result in these prior art systems from the fact that the tubes therein conduct the higher pressure medium. When a tube in such systems develops a leak, the release of the contained high pressure fluid produces a high velocity stream which, when it impinges upon adjacent tubes, cause ultimate failure of the latter by erosion thereby propagating component damage. Also, because the tubes contain the high pressure fluid, complex, expensive restraining structures must be provided, especially in units employing bayonet tube assemblies, to prevent the scabbard tubes from being projected under great force from the tube bundle in the event of a complete circumferential rupture of its wall.

When attempts have been made in prior art devices to ameliorate these last mentioned problems by arranging the heat exchanger components for flowing the low pressure heating medium through the tubes and circulation of the high pressure heating fluid exteriorly thereof within the shell, the heat transfer efficiency has been seriously reduced. This effect results from the undue heat exchange loss which occurs between the fresh high temperature liquid sodium that enters the unit and the lower temperature spent medium which is customarily conducted in close proximity to the fresh medium.

SUMMARY OF THE INVENTION

According to the present invention there is provided an improved heat exchanger design that is especially adapted for use of high temperature liquid metal as an operating medium. The organization is such as to minimize the effects of, and in some cases to completely avoid, the aforementioned, as well as other, problems inherent in prior art apparatus of the described type. The disclosed arrangement comprises a vertically elongated vessel that is divided into a high pressure region in which vaporizable fluid is evaporated and/or superheated and a low pressure region through which the liquid metal heating medium is circulated. The low pressure region of the unit includes a bundle of tube assemblies of novel constructuion whose external heat transfer surface is operably disposed in the high pressure region of the vessel and whose interior is arranged to provide flow paths for effectively circulating the liquid metal heating medium. The tube assemblies are of the bayonet-type in which the outer scabbard tube is a pressure member designed to withstand the highest expected system pressures and the inner bayonet tube is provided with double walls which, because they are exposed only to the low pressure medium, can be formed of reduced thickness. The walls of the inner tube cooperate with the outer tube to define concentrically spaced liquid metal flow paths through the tube assembly. The leading ends of the bayonet tube walls are sealedly interconnected to define an annulus disposed intermediate the liquid metal flow paths. This annulus is arranged to contain an inert gas that effectively insulates the respective flow paths to improve the heat transfer characteristics of the design.

There are described herein several diverse structural configurations for the high pressure region of the heat exchanger by means of which the present design is readily adapted for use as an evaporator, as a superheater, or as an integrated evaporator-superheater.

The various objects and advantages attendant with use of the invention will become apparent from the following description of several preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional elevational view of a shell and tube heat exchanger of the present invention adapted for use as an evaporator;

FIG. 2 is a sectional veiw of a typical tube assembly utilized in the heat exchanger of FIG. 1;

FIG. 3 is a sectional view of a heat exchanger of the present invention adapted for use in one form of evaporator-superheater organization; and

FIG. 4 is a sectional view of heat exchanger of the present invention adapted for use as another evaporator-superheater organization.

DESCRIPTION OF THE PREFERRED EMBODIMENT

It will be understood that like numerals will be used throughout the following description to identify like elements in the various described embodiments. It should also be understood that, while the described embodiments of the invention utilized sodium as the liquid metal heating medium, other molten metals and molten metal salts can also be utilized with corresponding efficacy.

Referring now to the drawings there is illustrated a shell and tube heat exchanger organization **10** adapted for the indirect transfer of heat from a high temperature heating fluid, such as liquid sodium, to a fluid to be heated. The heat exchanger **10** comprises a vertically elongated cylindrical shell assembly including an upper section **12** whose upper end is closed by an integral hemispherical closure cap **14** containing a vapor discharge nozzle **15,** a lower section **16** and a lower end closure **18** all of which cooperate to form an enclosed vessel. As shown, annular flanges **20, 22, 24** and **26** are disposed about the opposing ends of the respective sheel sections to mount detachable connectors (not shown) that facilitate assembly and disassembly of the shell structure. The interior of the vessel contains a high pressure tube sheet **28** that extends transversely of the vessel axis and whose outer peripheral edge is welded or otherwise attached to the adjacent wall surface of the shell to divide the interior of the vessel into a high pressure region, indicated as **30,** above the tube sheet and a low pressure region **32** therebelow. The two regions are so designeated for the reason that that region which contains the vaporizable fluid will be exposed to internal pressures on the order of 2500 psi while that containing the liquid sodium will be exposed to fluid pressures usually no greater than 100 psi. Therefore the upper shell section **12,** the high pressure tube sheet **28** and that portion of the lower shell section **16** disposed above the high pressure tube sheet are sized of a greater wall thickness than the remainder of the lower shell section **16** and the end closure **18.**

The low pressure region **32** of the vessel is,itself, divided into axially spaced plenums, indicated as inlet plenum **34** and outlet plenum **36,** by means of a low pressure tube sheet **38** that traverses the interior of the low pressure region and that may be detachably mounted upon an annular flange **40** which is secured to the inner surface of the lower shell section **16.** Appropriate seal means (not shown) may be embodied in the mounting structure to provide a fluid seal between the two plenums. nozzles **42** and **44** penetrate the walls of the shell section **16** and lower end clsoure **18** in communication with the respective plenums **34** and **36** to enable liquid sodium to be continuously circulated between the heat exchanger **10** and a heating source, such as a nuclear reactor (not shown), that employs liquid sodium as a coolant.

As illustrated in the drawings, liquid sodium is caused to flow through the heat exchanger **10** at a rate to produce a body of liquid in each of the respective plenums **34** and **36,** whose free surface is axially spaced below the adjacent tube sheet thereby defining gas sapces **46** and **48** in the plenums. Supply line **50** and **52** communicate with the respective gas spaces to supply inert gas, such as helium or argon, thereto whose function it is to provide an inert cover that blankets the liquid sodium in the respective plenums. This gas also serves to facilitate venting of the reaction products in the event of a system malfunction without an attendant release of sodium. The gas spaces still further serve to provide an insulation barrier between the respective regions of the vessel interior to minimize temperature differential therebetween. Also communicating with the gas spaces **46** and **48** are reaction product vent nozzles **54** and **56** containing rupture discs **57** that function to relieve pressure forces in the shell in the event of a component failure that results in the reactive mixture of sodium and water as will hereinafter be more fully explained.

The sodium inlet plenum **34** contains a flow distributor **58** that operates to uniformly distribute heating fluid to the tube assemblies and to promote quiescence in the free surface of the body of liquid sodium in the inlet plenum thereby to reduce the possibility of gas being readily admitted to the flow passages of the tube assemblies. The flow distributor **58** includes an impervious lower plate **60** that is suspended by an annular skirt **62** having circumferentially spaced openings **64** from an annular flange **66** that permits the member to be conveniently mounted between the end flanges **24** and **26** of the lower shell section **16** and lower end closure **18.**

Thermal energy is transferred between the low pressure region **32** of the vessel and the high pressure region **30** thereof by means of upstanding bayonet-type tube assemblies, indicated generally as **68,** that are arranged in a vertical bundle extending longitudinally into the high pressure region. The tube assemblies **68,** a typical one of which is shown in detail in FIG. **2,** each comprise an outer scabbard tube **70** that is attached by welding or other positive mechanical connection to the high pressure tube sheet **28.** The lower end **72** of the scabbard tube is open to communicate with the sodium outlet plenum **36** while its top end **74** is closed. An inner bayonet tube **76** extends coaxially into the interior of the scabbard tube **70.** It contains two concentrically spaced inner and outer walls, **78** and **80** respectively, that define an interior axial passage **82** and a concentric annulus **84** thereabout. The outer wall **80** of the bayonet tube **76** is concentrically spaced from the inner surface of the scabbard tube **70** to define a concentric annular flow passage **86** therebetween that communicates at its upper end with the axial passage **82.** As shown, the leading end **88** of bayonet tube contains an integral annular connecting joining the walls **78** and **80** thereby closing the upper end of the annulus **84.**

Each bayonet tube **76** is mounted within the vessel by attachment of the lower end of its outer wall **80** to the low pressure tube sheet **38.** This plates the annulus **84** in communication with the gas space **46** in the sodium inlet plenum **34** thereby to form an effective elongated thermal barrier between the passages **82** and **86** throughout the tube assembly. In order to effectively circulate liquid sodium through the passages **82** and **86** while at the same time preventing the entry of inert gas, the lower ends of the scabbard tube **70** and inner wall **78** of bayonet tube **76** should, as shown, extend below the free surfaces of the liquid bodies in the respective plenums thereby to seal the passages from the adjacent gas spaces.

The operation of the heat exchanger design thus far described is as follows . High temperature liquid sodium enters the inlet plenum **34** through inlet nozzle **42** and flows in series through the passages **82** and **86** in the tube assemblies **68** discharging into the outlet plenum **36** and thence from the unit through outlet nozzle **44.** In flowing through the tube assemblies **68** the liquid sodium is caused to give up part of its heat to the vaporizable fluid that circulates along one of the several diverse flow paths hereinafter described.

Because of the transfer of heat from the liquid sodium to the vaproizable fluid, the temperature level of the sodium decreases as it flows downwardly along the annular passage **86** through the tube assemblies **68.** In

spite of this fact however, the transfer of heat from the higher temperature heating fluid flowing along the axial passage to the fluid in passage **86** is minimized by the thermal barrier presented by the containment of gas in the annulus **84** between the passages **82** and **86.**

As shown in FIG. **1** it is contemplated to dispose the inlet to the axial passage **82** in one, or possibly a few, of the bayonet tubes **76** at a higher level in the sodium inlet plenum **34** than the inlet to the remaining tubes in order to prevent the evacuation of sodium from all of the tube assemblies **68** in the event of an operational transient that results in a lowering of the free surface of liquid sodlium in the inlet plenum **34.** By disposing one or more of the inlets to the passages **82** at a higher level in the inlet plenum **34** than the remaining tube assemblies **68** there is provided a means for releasing the inert gas from the gas space **46** in the inlet plenum **34** and passing it into the gas space **48** in the outlet plenum **36** thereby preventing the free surfaces of the liquid sodium body to recede further to an undesirable level.

To enhance heat transfer in unit, the tube assemblies **68** can each be enclosed by shroud tubes **90** that are concentrically spaced from the outer surface of each scabbard tube **70** thus to define an annular passage **92** between the two members for conducting vaporizable fluid in close proximity to the heatingsurface presented by the tubes **70.** The shroud tubes **90** are bottom supported on a support plate **94** disposed in the lower end of the high pressure region **30** and which is spaced vertically above the high pressure tube sheet **28** to define a vaporizable fluid inlet plenum **96** at the lower end of the region **30.** Openings **98** are provided in the support plate **94** to permit the entry of vaporizable fluid into the passages **92** between the shroud tubes and the scabbard tubes **70.**

The above-described heat exchanger design is readily adaptable for use as an evaporator, as a tandem-connnected evaporator-superheater arrangement, or as an integral-evaporator superheater arrangement. The heat exchanger **10** illustrated in FIG. **1** has its high pressure region **30** arranged such that the unit can be utilized as an evaporator. A feed liquid inlet nozzle **100** communicates with the vaporizable fluid inlet plenum **96** intermediate the high pressure tube sheet **28** and the support plate **94** to supply fluid to be heated to the unit. This fluid is caused to flow from the inlet plenum **96** through the annular passages **92** between the shroud tubes **70** where heat is extracted from the high temperature liquid sodium that circulates through the interior of the tube assemblies **68** to transform some of the feed liquid into vapor. In order to insulate the passages **92,** the tube bundle may be enclosed by a cylindrical receptacle **101** having an open upper end and whose lower end is attached to the support plate **94.** During operation of the evaporator this receptacle is caused to be filled with a substantially stagnant body of liquid that immerses the shroud tubes **90** and thereby forms an effective thermal barrier.

An inverted U-shaped cylindrical baffle **102** encloses the tube bundle in concentrically spaced relation between the receptacle **101** and the inner surface of the upper shell section **12** to define a pair of concentric annular flow passages **104** and **106.** These flow passages serve to conduct the vaporizable fluid from the discharge end of passages **92** to a vapor collection space **108** at the upper end of the vessel interior from whence the same is discharged to a point of use through the vapor discharge nozzle **15.** The lower end of the baffle **102** is spaced from the high pressure tube sheet **28** to interconnect the passages **104** and **106** and to cause the generated mixture of vapor and liquid to undergo an abrupt change of direction in flowing through the passages whereby much of the entrained liquid is separated from the mixture. A liquid discharge nozzle **110** penetrates the lower end of the upper shell section **12** to remove the separated liquid from the vessel interior. This liquid is commonly returned to the high pressure region **30** of the unit for recirculation therethrough in mixed relation with the fresh feed liquid admitted through inlet nozzle **100.** Final separation of moisture from the vapor is effected by passing the vapor entering the collection space **108** through a screen or other form of mechanical drier **112** prior to its being discharged from the nozzle **15.**

It will be appreciated from the foregoing description that the heat exchanger design of the present invention provides several advantageous features not possessed by liquid metal operated shell and tube heat exchangers of the prior art. Because the heat exchanger is designed for the circulation of liquid metal heating fluid through the interior of the tube assemblies, rather than for circulating this fluid exteriorly thereof, a significantly reduce amount of this expensive material is required for effective operation of the plant. In addition to the material cost savings, this reduction in inventory improves plant operation by enabling more rapid response to operational changes in the system due to the fact that a lesser amount of stored heat is contained in the heating medium.

The reduced amounts of liquid metal circulated through the system further result in improved plant safety characteristics. First, the smaller volume of sodium in the tube limits the amount available for reaction with water in the event of a component malfunction that results in mixing of the two reactive fluids. Secondly, the small amounts of sodium contained in the inlet and outlet plenums provide relatively short paths along which the reaction products must flow to escape into the inert gas spaces in the respective plenums prior to their venting through the vent nozzles. Thirdly, since the amounts of reaction products capable of being produced are limited, the attendant forces on the pressure parts of the apparatus are correspondingly reduced thereby reducing the strength requirements of the respective components. In addition to improving plant safety conditions, this latter feature also results in a reduction in equipment costs since the components can be designed to accommodate lower design pressures.

Other advantageous features derived from use of the hereindescribed heat exchanger design result from the fact that the tubular elements are caused to conduct the lower pressure fluid while the higher pressure medium is contained in that region of the vessel that surrounds the tubular elements. Most importantly, failure of a single tube cannot propagate damage to surrounding tubes due to tube wall erosion that would otherwise be caused by the impingement of high pressure, high velocity streams of fluid released from the ruptured tube. Additionally, by retaining the high pressure fluid outside the tubular elements, the latter will not be subject to tensile stresses that could otherwise worsen internal weakness in the tube wall. Moreover, even in the event of a complete circumferential rupture or break in the pressure tube, the same will not be subjected to in-

ternal forces that would tend to rapidly project it from its mounting in the tube bundle. Still further, having the high pressure medium outside the tubes assists in rapidly evacuating liquid sodium from a malfunctioned tube.

FIGS. 3 and 4 of the drawing illustrate other vapor generating equipment that utilize the hereindescribed heat exchanger design and to which the aforementioned advantageous features similarly attach. In FIG. 3 there is shown an organization incorporating two heat exchangers according to the invention that are connected in tandem and operate to produce superheated vapor. This heat exchanger, indicated as **10***a*, serves as an evaporator in which feed liquid is evaporated while superheating occurs in the interconnected heat exchanger, indicated as **10***b*. The structural configuration of the heat exchanger **10***a* is substantially the same as that indicated as **10** previously described with regard to FIG. **1** but, since no vapor drying is effected in the vessel, it is devoid of the cylindrical baffle **102.** The pressure part arrangement in the high pressure region **30** of the heat exchanger **10***b*, on the other hand, is somewhat revised as hereinafter explained to accommodate heating of the vapor received from the evaporator **10***a*. As shown, the vapor produced in the evaporator **10***a* which emerges from its vapor outlet **15** is passed from line **114** to a vapor drum **116** of substantially conventional design within which the generated mixture is separated with the liquid being recirculated by means of pump **118** through line **120** to the feed liquid inlet nozzle **100** of the evaporator **10***a*. Feed liquid is introduced through line **122** to the drum **116** where it is mixed with the liquid to be recirculated prior to conducting the same to the inlet nozzle **100.** The vapor emerging from the vapor drum **116** enters the high pressure region **30** of the superheater **10***b* through line **123** and vapor inlet nozzle **124** and passes into an annular passage **126** defined by cylindrical baffle **128** that is concentrically spaced between the wall of the upper shell section **12** and the bundle of tube assemblies **68.** The lower end of the baffle **128** is supportedly attached to the support plate **94** that mounts the shroud tubes **90.** A plurality of circumferentially spaced openings **130** are provided in the support plate **94** to effect communication between the passage **126** and the vaporizable fluid inlet plenum **96.** From the inlet plenum **96** the vapor flows through the annular passages **92** about the scabbard tubes **70** where heat is extracted from the circulating liquid sodium for superheating. A conduit connection **132** connects the upper end of the baffle **128** to the vapor discharge nozzle **15** for conducting the product superheated vapor to a point of use.

Although independent connections may be made between the respective heat exchangers **10***a* and **10***b* and the high temperature source of liquid sodium, reduced piping requirements result if the low pressure regions **32** of the respective heat exchangers are connected as shown for series flow of the heating fluid. Note that in the illustrated organization fresh high temperature heating fluid enters the system through the sodium inlet nozzle **42** of the superheater **10***b* and, after circulating through this unit, exits through outlet nozzle **44** which connects directly with the sodium inlet nozzle **42** of the evaporator **10***a* by means of line **134.** The heating fluid discharged from the sodium outlet nozzle **44** of evaporator **10***a* is then conducted through line **136** back to the heat source to complete the circulation system.

FIG. **4** illustrates an organization utilizing the same heat exchanger design but in which vaporizable fluid can be both evaporated and superheated within the same vessel. In this arrangement the high pressure region **30** of the heat exchanger, indicated as **10***c*, contains a first outer cylindrical baffle **138,** similar to baffle **102** in the FIG. **1** arrangement, which is concentrically spaced between the shell wall and receptacle **101** to form vaporizable fluid flow passages **104** and **106.** The top of the baffle **138** is open and contains a vapor drier assembly **140** through which the saturated fluid is directed on a downward course. A transverse divider plate **142** attaches to the interior of the baffle **138** intermediate its ends to divide the contained space into a lower evaporation space **144** and an upper superheating space **146.** A second cylindrical baffle **148** is disposed in the superheating space **146** in concentrically spaced relation between the baffle **138** and the upper portion of the tube bundle to form concentric flow passage **104.** The baffle **148** attaches a tube support plate **152** at its lower end for mounting additional shroud tubes **90** in this region of the unit. A connecting conduit **154** penetrates the upper end of baffle **148** for conducting superheated vapor to the vapor discharge nozzle **15.**

The feed liquid admitted to the inlet plenum **96** through nozzle **100** is caused to flow through the passages **92** within the shroud tubes **90** whereby it extracts heat from that portion of the tube assemblies **68** disposed within the evaporation space **144.** The vapor-liquid mixture that emerges from the passages **92** flows via concentric flow passages **104** and **106** to the top of the vessel where it is directed downwardly through the drier apparatus **140.** The dried fluid is directed into the superheating space **146** along passage **104** where it enters the respective passages **92** within the shroud tubes **90.** In flowing along the passages **92** heat is transferred to the vapor from the heating fluid flowing through the upper portion of the tube assemblies **68** that are disposed within this region of the vessel. The superheated vapor is conducted to the discharge nozzle **15** through conduit **154** from whence it is conducted to a point of use.

While several preferred embodiments of the present invention have been illustrated and described herein, it is to be understood that the respective descriptions are merely illustrative and that variations and modifications may be made therein without departing from the spirit and scope of the invention as recited in the following claims.

What is claimed is:

1. A shell and tube heat exchanger organization in which heating fluid is circulated in heat exchange relation with a fluid to be heated comprising:

a. a shell;

b. an outer tube having an open end and a closed end housed within said shell;

c. an inner tube having a pair of concentrically spaced walls defining an axial passage and a first annulus concentrically spaced therefrom and means for closing one end of said first annulus;

d. said inner tube having an external diameter less than that of the internal diameter of said outer tube and extending coaxially into said outer tube from the open end thereof with its leading end axially spaced from the closed end of said outer tube to

define a second annulus in fluid communication with said axial passage;

e. means to direct a flow of heating fluid through said axial passage and said second annulus;

f. means for passing an inert gas into said first annulus; and

g. means for circulating fluid to be heated through said shell externally of said outer tube in heat exchange relation therewith;

said shell includes means forming a plenum in fluid communication with said axial passage and said second annulus in said inner tube, said plenum containing a body of heating fluid therein and a gas space thereabove and wherein the axial passage through said inner tube extends below the level of said body of heating fluid and said second annulus communicates with said gas space, said plenum having means for venting said gas space.

2. An apparatus according to claim **1,** wherein said shell is elongated along the vertical axis; said heating fluid is a molten metal; and said fluid to be heated is a vaporizable fluid, and additionally including, means for dividing the interior of said shell into axially spaced high pressure and low pressure regions, said molten metal circulated in said low pressure region and said vaporizable fluid circulated in said high pressure region.

3. Apparatus according to claim **2** wherein means for forming a plenum divides said low pressure region into axially spaced plenums, said inner and outer tubes define tube assemblies; and the axial passage in said inner tube communicates with one of said plenums and said second annulus communicates with the other of said plenums, and additionally including

a. a plurality of elongated shroud tubes enclosing said tube assemblies to define annular fluid passages thereabout; and

b. means forming a support plate axially spaced from said main tube sheet in said high pressure region of said shell and forming a vaporizable fluid inlet plenum, said support plate attaching said shroud tubes with their lower ends in communication with said fluid inlet plenum.

4. An apparatus according to claim **3,** wherein said high pressure region is positioned above said low pressure region, said low pressure region axially spaced plenums are divided into a lower inlet plenum intermediate said inlet plenum and said high pressure region.

5. Apparatus according to claim **3** in which the inner walls of some of said inner tubes extend to reduced depths below the level of molten metal in said plenums than others of said inner tubes.

6. Apparatus according to claim **3** including:

a. a collection space adjacent the upper end of said high pressure region of said shell;

b. a vapor outlet from said collection space; and

c. inverted, domed baffle means spacedly enclosing said bundle of tube assemblies in concentrically spaced relation from the shell wall and cooperating therewith to form a vapor discharge passage in which the fluid undergoes an abrupt change of direction in flowing from said annular fluid passages to said collection space.

7. Apparatus according to claim **6** wherein the lower end of said baffle means extends to a position slightly spaced above said third tube sheet for washing the axial length of said shell wall with fluid at a substantially uniform temperature.

8. Apparatus according to claim **3** including:

a. means dividing the high pressure region of said shell into an evaporator portion and a superheater portion axially spaced therefrom;

b. said tube assemblies extending longitudinally through both of said portions;

c. means for directing said vaporizable fluid successively through said evaporator portion and said superheater portion; and

d. means for withdrawing superheater vapor from said superheater portion.

9. Apparatus according to claim **8** in which said evaporator portion is disposed intermediate said vaporizable inlet plenum and said superheater portion and said apparatus includes:

a. a first annular baffle surrounding said tube assembly bundle in concentrically spaced relation from the wall of said shell, the ends of said baffle terminating short of the lower and upper ends of said high pressure region to define an outer annular passage substantially coextensive with said high pressure region;

b. a second annular baffle concentrically spaced from said first baffle and surrounding said tube assembly bundle in said superheater portion to define an interior flow passage containing said tube assemblies and an intermediate flow passage between said interior and said outer flow passages;

c. means connecting said outer flow passage, said intermediate flow passage and said interior flow passage in series; and

d. means for conducting superheated vapor from said interior flow passage.

10. Apparatus according to claim **9** including a transverse baffle having its periphery sealingly connected to the inner wall of said first annular baffle, said transverse baffle being disposed intermediate the ends of said annular baffle and separating said evaporator portion of said shell from the superheater portion thereof.

11. Apparatus for evaporating and superheating a vaporizable fluid by the indirect exchange of heat from a molten metal comprising:

a. a pair of structurally similar heat exchangers defined in claim **2** respectively and defining an evaporator and a superheater,

b. said means for circulating vaporizable fluid through said apparatus including:

i. means for supplying said fluid as a liquid to the high pressure region of said evaporator,

ii. means connecting the high pressure regions of said heat exchangers for series flow of vaporizable fluid, and

iii. means for withdrawing said fluid as superheated vapor from the high pressure region of said superheater.

12. Apparatus according to claim **11** including vapor-liquid separating means interposed in said vaporizable fluid circulating means between said heat exchangers, and means for passing liquid from said separating means to the high pressure region of said evaporator.

13. Apparatus according to claim **12** wherein said molten metal circulating means includes means connecting the low pressure regions of said heat exchangers for series flow from said superheater to said evaporator.

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