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Creek

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[54] **LMFBR INTERMEDIATE HEAT EXCHANGER**

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[52] **U.S. Cl.** **165/83,** 165/158, 122/32

[51] **Int. Cl.** **F28b 7/00**

[58] **Field of Search** .... 165/83, 158, 159; 122/32, 122/34 I

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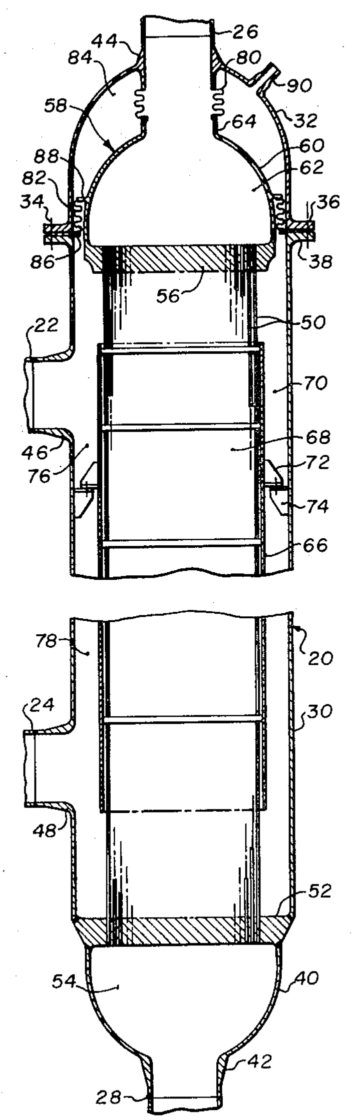
[57] **ABSTRACT**

A heat exchanger of the shell and tube type and particularly adapted to employ liquid metal as the heating fluid is provided with a floating head for connecting the ends of the heat exchanger tubes whereby stresses on the tubes due to thermally induced differential movements between the tubes and the shell are prevented. A pair of mutually spaced expansion bellows are connected between the floating head and the shell to define a closed space within which an inert gas is maintained. The bellows pair provides a double barrier between the heating fluid and the fluid to be heated to prevent admixture of the two fluids while the inert gas space intermediate the bellows provides means for detecting a bellows failure enabling the ruptured bellows to be replaced without danger of mixing the two fluids.

12 Claims, 4 Drawing Figures



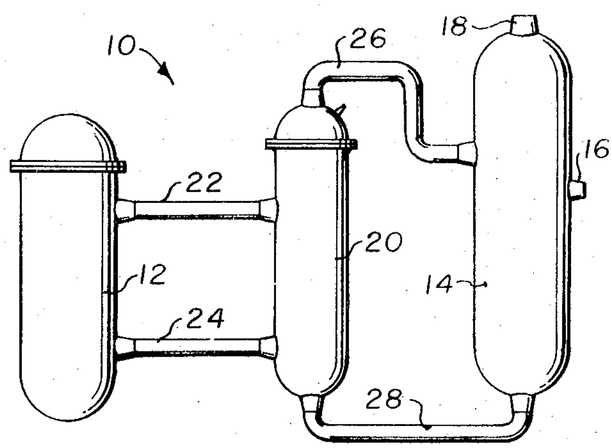


FIG. 1

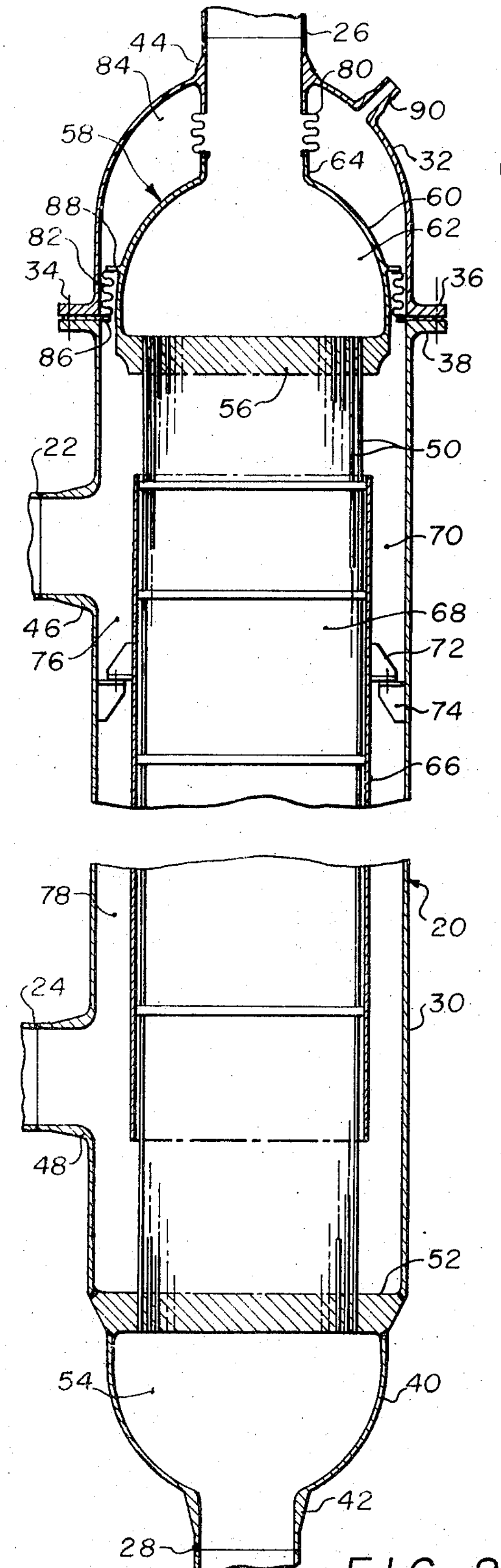


FIG. 2

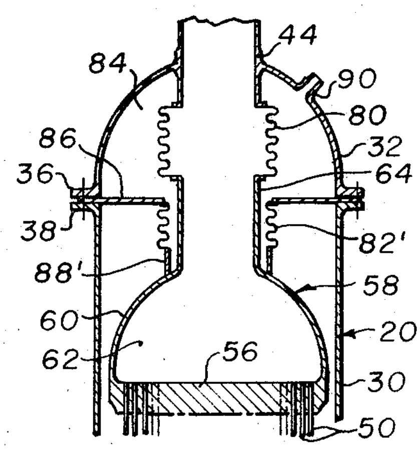


FIG. 3

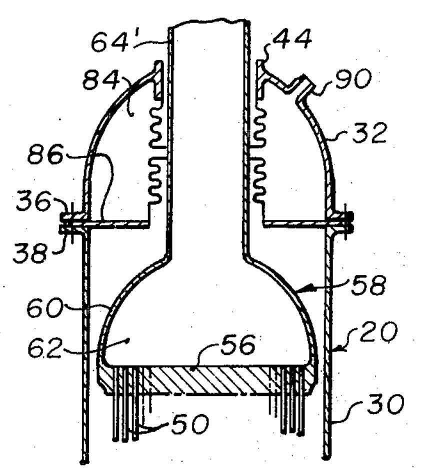


FIG. 4

LMFBR INTERMEDIATE HEAT EXCHANGER

BACKGROUND OF THE INVENTION

In sodium operated nuclear power plants it is customary to employ an intermediate heat exchanger interconnected between the nuclear reactor and the vapor generator. Such heat exchangers normally employ liquid sodium as both of the heat transfer fluids. It is the function of the intermediate heat exchanger to effect the transfer of heat from the liquid sodium primary coolant which is radioactive due to the fact that it is circulated through the reactor core to the liquid sodium of the secondary circuit whose fluid must be maintained relatively free of radioactivity since this latter fluid is circulated through the vapor generators of the plant where it transfers heat to the water to be evaporated. Because of the fact that the intermediate heat exchanger is exposed to temperature variations attendant in both liquid sodium circuits, it is often subjected to temperature gradients and thermal transients of large magnitude during periods of normal plant operation. These adverse conditions are even more severe during abnormal or upset occurrences in plant operation. One of the most serious problems encountered by the designers of plant components, therefore, is that of how to render the intermediate heat exchanger safe from undue stress impositions that occur during these temperature excursions as a result of the differential growth experienced between the tubes and the vessel shell.

Intermediate heat exchangers heretofore made in the art have sought to avoid these problems by providing the tubes employed in such apparatus with expansion bends to permit them to flex during periods of differential thermal growth. Such measures have not been totally successful due to the fact that in addition to imposing bending stresses on the tubes, certain other undesirable features are thereby introduced to the apparatus. For example, the presence of bends in the tubes subjects them to the problem of vibration. Vibrations are induced in the tubes to a large extent by the impact thereon of the fluid flowing externally of the tubes. Also contributing to the inducement of vibration are the forces imposed on the tubes by the internal fluid in its having to undergo abrupt changes of direction in flowing through the tubes. To offset the possible effects of vibration it is therefore necessary to provide complex, expensive tube support structures particularly designed to accommodate tube bends. This adds appreciably to the consruction costs of the apparatus.

SUMMARY OF THE INVENTION

The present invention provides an improved heat exchanger design that avoids the aforementioned problems. Heat exchangers constructed according to the invention comprise a shell and tube arrangement in which the tube bundle includes a plurality of straight, parallel tubes that extend between a fixed tube sheet at one end and a tube sheet forming part of a floating head at the other end. Because of this arrangement the tubes are free to incur thermal growth independently of the growth experienced by the shell thereby removing the danger of subjecting the tubes to possible failure caused by buckling or undue tensile loadings. The floating head is connected to the shell by a pair of mutually spaced bellows members that cooperate to define an enclosed space within which an inert gas is maintained during periods of plant operation. The provision of a gas space permits monitoring of the structural integrity of the respective bellows members by providing means for detecting leakage of one of the heat transfer fluids into the gas space in the event of failure of one of the bellows members. Because two bellows members define the gas space mixture between the two fluids in the event of failure of one of them is prevented by the other bellows member that remains intact thereby permitting plant operation to be conveniently terminated for necessary repair without the attendant creation of a dangerous condition.

The specific ojects and advantages of the invention will become apparent to those skilled in the art upon consideration of the following description together with the accompanying drawings wherein several embodiments of the invention are described.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of a liquid metal operated vapor supply system;

FIG. **2** is a sectional elevational view of the intermediate heat exchanger utilized in the vapor supply system of FIG. **1**;

FIG. **3** is a partial sectional elevational view of another embodiment of a heat exchanger constructed according to the invention; and

FIG. **4** is a partial sectional elevational view of still another embodiment of a heat exchanger constructed according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** of the drawing illustrates a nuclear operated vapor supply system **10** in which liquid metal, such as molten sodium, is utilized as the heat transfer medium between the heat generated by the nuclear reaction and the fluid to be evaporated. The system **10** includes a nuclear reactor **12** in which the reaction occurs and a vapor generator **14** in which vaporizable fluid, most commonly waer, which enters the system at inlet **16,** is evaporated, and possibly superheated, before exiting the system at outlet **18** from whence it is conducted to a point of use.

In order to protect against the possible release of harmful radioactive elements from the liquid metal coolant, termed the primary coolant, that circulates through the reactor core it is customary in such systems to employ an intermediate heat exchanger, indicated as **20.** It is the function of the intermediate heat exchanger **20** to transfer heat from the contaminated primary coolant to a secondary fluid which may also be liquid sodium and which, because it is generally isolated from the primary coolant, will be substantially free of radioactivity. In the described system primary coolant is continuously circulated between the reactor **12** and the intermediate heat exchanger **20** by circulating lines **22** and **24.** The intermediate heat exchanger **20** is, in turn, connected for continuous circulation of the secondary fluid through the vapor generator **14** by lines **26** and **28.**

Going now to FIG. **2** of the drawing the intermediate heat exchanger **20** which is constructed according to the invention is illustrated in greater detail. It comprises a substantially closed vessel formed by a vertically elongated shell **30** of circular cross section and an upper closure cover **32** that is detachably secured to the shell by connectors, represented by center lines **34**, that are circumferentially spaced about mating end flanges **36** and **38** on their respective members. The lower end of the shell **30** is closed by a hemispherical closure **40** that may be integrally attached to the shell as by welding and which contains a secondary fluid inlet nozzle **42** that connects with circulating line **28** from the vapor generator **14**. An outlet nozzle **44** is formed in the upper closure cover **32** for the discharge of heated secondary fluid from the intermediate heat exchanger **20**. This nozzle connects with line **26** that conducts the heated secondary fluid to the vapor generator **14**. The circulating lines **22** and **24** which conduct the primary coolant between the reactor **12** and the intermediate heat exchanger **20** communicate with the vessel by attachment to heating fluid inlet and outlet nozzles **46** and **48** respectively that penetrate the shell wall at longitudinally spaced locations.

A bundle of vertically elongated, straight, parallel tubes **50** adapted to conduct the secondary fluid to be heated is disposed within the vessel. The lower end of the tubes **50** are attached to a tube sheet **52** that extends transversely of the vessel axis and which is integrally attached about its periphery between the shell **30** and lower end closure **40**. This tube sheet **52** cooperates with the lower end closure **40** to define a secondary fluid inlet plenum **54** at the lower end of the vessel.

The upper end of the tubes **50** connect with a second tube sheet **56** that forms part of a floating head, indicated generally as **58**, disposed in the upper region of the vessel and which, because it is not rigidly attached to the shell **30**, can undergo thermally induced movements independently of those induced in the shell. The floating head **58** additionally includes a domed cover **60** that cooperates with the tube sheet **56** to form a secondary fluid outlet plenum **62**. Discharge conduit **64** is formed in the cover **60** and is disposed in axial alignment with the outlet nozzle **44**. As shown, the discharge conduit **64** is connected to the nozzle **44** by a bellows member, a description of which is more fully provided hereinafter.

As shown in FIG. **2** the flow path of the primary coolant or heating fluid through the interior of the vessel is defined by an elongated cylindrical baffle **66** that surrounds the tube bundle in spaced relation from the shell **30** thereby defining concentrically disposed axial and annular flow regions, indicated as **68** and **70** respectively. The baffle **66** is suspendedly supported from the shell wall by a pair of opposed annular supports **72** and **74** having mating surfaces that serve to effectively separate the upper portion **76** of the annular flow region **70** from the lower portion **78** thereof. By means of this arrangement primary coolant from the reactor **12** that enters the intermediate heat exchanger **20** through inlet nozzle **46** is caused to flow seriatim through the upper portion **76** of the annular flow region **70**, through the axial flow region **68** in indirect heat transfer relation with the fluid flowing through the tubes **50**, and thence through the lower portion **78** from whence it exits the vessel through outlet nozzle **48** for circulation back to the reactor **12**.

According to the invention a pair of mutually spaced annular bellows **80** and **82** are disposed within the vessel and cooperate to define a space or plenum **84** at the upper end thereof. The bellows **80** and **82** are both arranged for axial deflection and are disposed to have one end connected in fixed relation to the shell **30** and the other end attached to the floating head **58** whereby any differential movement between the shell and the floating head can be accommodated. In the embodiment of the invention illustrated in FIG. **2** the upper bellows **80** is connected at its opposite ends between the floating head discharge conduit **64** and the outlet nozzle **44** in the upper closure cover **32**. The lower bellows **82**, which is of a diameter greater than that of the upper bellows **80**, is attached at one end to an annular plate **86** detachably mounted between the shell and closure end flanges **36** and **38** and its other end attached to an annular ring **88** that is integrally formed on the external surface of the floating head cover **60**.

By providing a pair of bellows within the vessel in the manner described a double barrier is presented for preventing the possible admixture of the respective operating fluids that are circulated through the heat exchanger. Each bellows member is provided with sufficient strength to be capable of independently withstanding the stresses imposed thereon by the respective operating fluids. Therefore, in the event of failure of one of the bellows members, fluid leakage of one operating fluid into the flow path of the other will be prevented by the obstruction provided by the bellows member that remains intact.

Moreover, the present invention provides means for monitoring the structural integrity of the respective bellows members in that means, indicated as inlet nozzle **90**, is provided for maintaining an inert gas, such as helium or argon, in the space **84**. Conventional means (not shown) can be installed for monitoring the gas space for the presence of sodium or sodium vapor or, alternately, for pressure changes that may occur within the space thereby to indicate the occurrence of a failure in one of the bellows members. Upon detection of a failure, the operation of the plant can be terminated in a slow, deliberate manner and the failed bellows member repaired or replaced without danger of mixing the two operating fluids.

The gas space **84** is desirably maintained at a fluid pressure lower than the fluid pressure of either of the primary coolant or the secondary fluid. In this mode of operation leakage across either bellows will pass into the gas space **84** where it can easily be detected. When leakage fluid is detected in the gas space the pressure of the inert gas admitted to the space can be adjusted to match the pressure across the leaking bellows thereby to reduce the rate of leakage. In this way the heat exchanger is thus capable of continuing operating with one bellows intact until such time that the normal shutdown of the unit can be effected.

Alternatively, the inert gas within the space **84** can be maintained at a pressure level approximately equal to the fluid pressure of either one of the heat transfer fluids. This mode of operation has the advantage that the bellows member interposed between the gas and the fluid whose pressure is approximated in the gas space is subjected to no pressure load, but instead only to loads imposed by the axial deflection of the member. This characteristic naturally will extend the life of the effected bellows member or, alternatively, the bellows can be formed of a material having less stringent strength requirements thereby reducing the cost of the member.

In FIGS. 3 and 4 of the drawing two other embodiments of the present invention are illustrated. In these figures only the upper region of the heat exchanger is shown. It should be understood, however, that the remainder of the heat exchanger construction is substantially the same as that of the apparatus disclosed in FIG. 1. In the FIG. 3 embodiment the lower bellows, here indicated as **84'**, has its opposite ends attached between the annular plate **86** which is mounted between the shell and cover end flanges **36** and **38**, and the annular ring **88'** that is integrally formed on the floating head **58**. The ring **88'** is located within the vessel on the opposite side of the annular plate **86** from its position in the FIG. 1 embodiment. In this arrangement the disposition of the members is such that the bellows member **82** can be formed of the same size and will be caused to undergo substantially identical deflections with the bellows member **80** in accommodating differential movements between the shell and floating head thereby facilitating the selection of the bellows members by the designer of the apparatus.

The embodiment of FIG. 4 is particularly adapted for use in a heat exchanger in which one of the fluids is at a significantly higher pressure than that of the other fluid thereby increasing the possibility of fluid admixture in the event of failure of one of the components. In this embodiment the discharge conduit, indicated as **64'** formed on the floating head **58** is axially elongated to a greater extent than the corresponding member in the other embodiments and extends through the outlet nozzle **44** in concentrically spaced relation thereto. The bellows members **80** and **82** both have one end attached to the conduit **64'** with their other ends connected to the nozzle **44** and annular plate **86** respectively. The function of the gas spaces **84** in each of the alternate embodiments of FIGS. 3 and 4 is exactly the same as that of the FIG. 1 embodiment.

It will be understood that various changes in the details, materials and arrangements of parts which have been herein described and illustrated in order to explain the nature of the invention may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A heat exchanger for the indirect transfer of heat from a heating fluid to a fluid to be heated comprising:

a. an elongated shell defining a pressure vessel having a heated fluid outlet nozzle adjacent one end thereof;

b. a pair of axially spaced tube sheets disposed within said vessel, one of said tube sheets being fixedly attached to said shell and the other of said tube sheets cooperating with a closure cover to form a floating head defining a heated fluid outlet plenum;

c. a bundle of substantially parallel tubes having their opposite ends attached to said tube sheets;

d. means for circulating heating fluid through said vessel exteriorly of said tubes;

e. means for passing fluid to be heated through said tubes in indirect heat transfer relation to said heating fluid;

f. means establishing fluid communication between said heated fluid outlet nozzle and said plenum including a first annular bellows connected between said floating head and said shell;

g. a second annular bellows connected between said floating head and said shell in spaced relation from said first bellows and cooperating therewith to define a substantially closed space therebetween; and

h. means for supplying an inert gas to said closed space.

2. A heat exchanger according to claim **1** in which said first bellows is interconnected between said floating head closure cover and said heated fluid outlet nozzle.

3. A heat exchanger according to claim **1** in which said shell includes a removable end closure detachably secured thereto and said second bellows is interconnected between said floating head and the interface between said end closure and said shell.

4. A heat exchanger according to claim **1** including an annular cylindrical baffle surrounding said tube bundle in concentrically spaced relation to the wall of said shell to define a pair of concentric flow paths through said shell; and means for suspendedly supporting said cylindrical baffle from the wall of said shell.

5. A heat exchanger according to claim **1** in which said heating fluid is liquid sodium.

6. A heat exchanger according to claim **5** in which said heated fluid is liquid sodium maintained at a fluid pressure greater than that of said heating fluid.

7. A heat exchanger according to claim **6** in which said inert gas is maintained at a lower fluid pressure than that of either said heating fluid or said fluid to be heated.

8. A heat exchanger according to claim **6** in which said inert gas is maintained at a fluid pressure approximately equal to that of one of the heat transfer fluids.

9. A heat exchanger according to claim **3** in which said floating head includes a discharge conduit axially aligned with said heated fluid outlet; means connecting said first annular bellows between said discharge conduit; an annular plate secured between said shell and said end closure; and means connecting said second annular bellows between said floating head and said annular plate.

10. A heat exchanger according to claim **9** in which said second annular bellows connects to said floating head on the side of said annular plate adjacent said first annular bellows whereby oppositely directed deflections are induced in said first and second bellows by relative movements between said floating head and said shell.

11. A heat exchanger according to claim **9** in which said second annular bellows connects to said floating head on the side of said annular plate remote from said first annular bellows whereby corresponding deflections are induced in said first and second bellows by relative movements between said floating head and said shell.

12. A heat exchanger according to claim **9** in which said floating head discharge conduit extends in concentrically spaced relation through said heated fluid outlet and said first and second annular bellows are connected at one end to said discharge conduit and at their other ends to said heated fluid outlet nozzle and said annular plate respectively.

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