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Anderson et al.

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[54] **HEAT EXCHANGER**

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[52] **U.S. Cl.** **165/82,** 165/158, 165/159, 165/176, 165/165

[51] **Int. Cl.** **F28f 9/22**

[58] **Field of Search** 165/164, 165, 82, 165/162, 176, 158, 159

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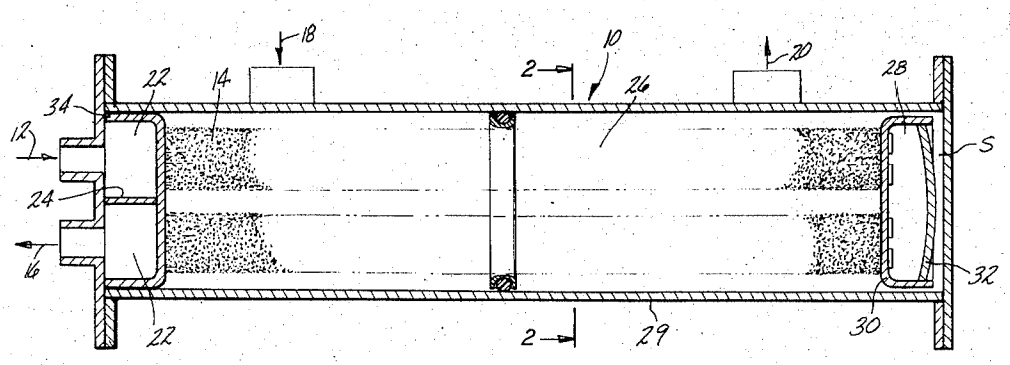
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[57] **ABSTRACT**

This invention relates to heat exchangers, and more particularly to an improved heat exchanger having tubular elements and a pervious body of material therein and wherein fatigue cracking of the tubular elements is substantially eliminated.

3 Claims, 8 Drawing Figures



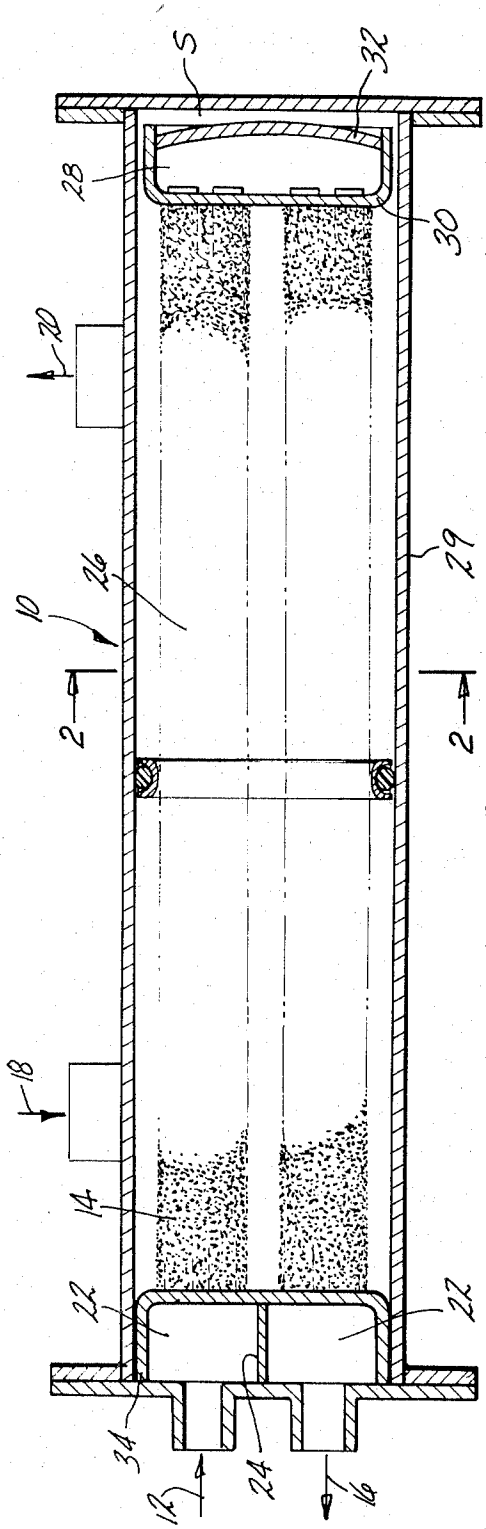


FIG-1

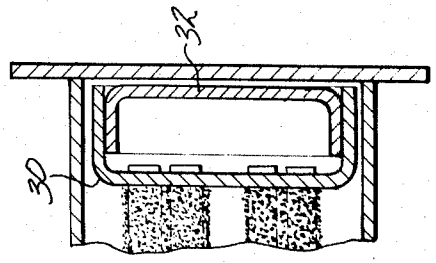


FIG-4

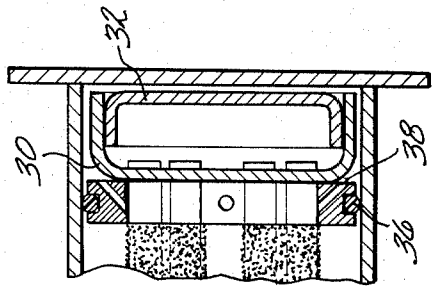


FIG-5

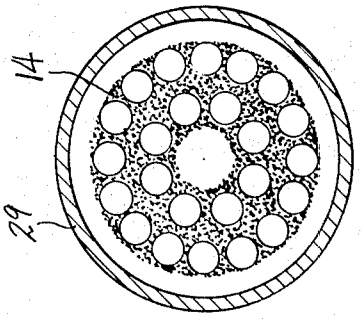


FIG-2

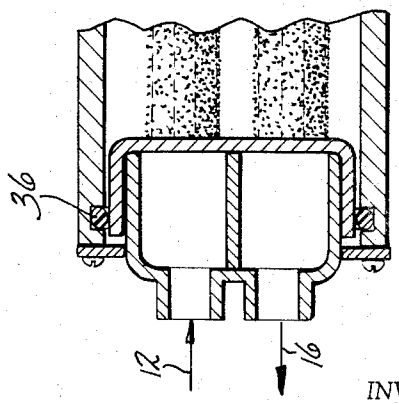


FIG-3

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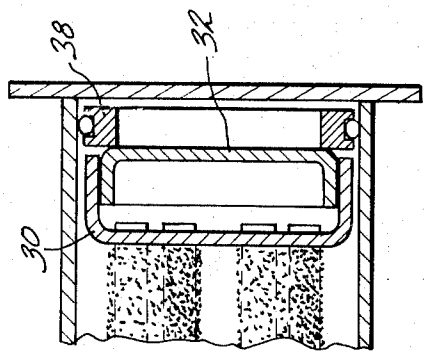


FIG-6

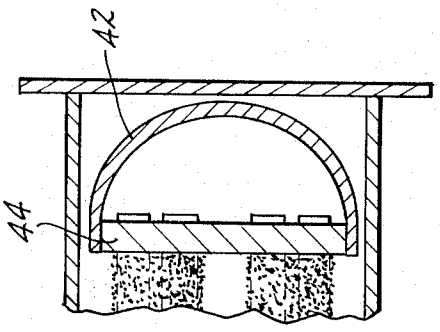


FIG-8

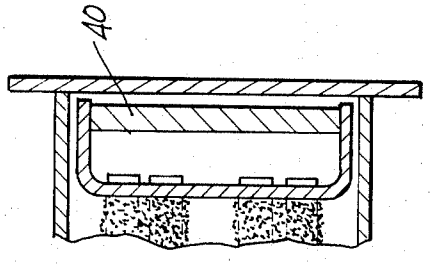


FIG-7

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HEAT EXCHANGER

As is known in the heat exchanger art the greatest heat exchange is achieved by providing the maximum possible area of material across which the desired heat exchange may take place. Various devices have been employed so to increase the material area, such as, for example, fins or corrugations across which pass the media between which the heat exchange is to take place. It has been found, however, that greatly increased heat transfer can instead be achieved by employing a body of pervious material having interconnecting voids as shown for example in U.S. Pat. No. 3,306,353. Such a body of pervious material presents a large number of faces, and hence a large surface area, for heat exchange purposes.

As is also known in the heat exchanger art, however, high stress levels may occur since the heat exchange medium flowing on the outside of the tubes during operation is at different temperature level than that of the heat exchange medium flowing on the inside of the tubes. Severe conditions of this type can and often does result in thermal stress of the tubes when the heat exchange operation is cyclic in nature. This occurs when one or both of the heat exchange mediums is subject to periodic flow or when there is complete stoppage of the flow of one or both of the mediums. Stresses are then created by the thermal expansion differences between the shell and the core which may result in fatigue cracks through the wall of the tubes adjacent the surface of the header which is in contact with the heat exchange medium flowing around the tubes. The crack may thus allow one heat exchange medium to mix with the other which naturally creates an untenable situation.

In the conventional heat exchanger art not employing a body of pervious material the concept of a floating head for severe conditions has frequently been employed wherein the heat exchanger core is free to expand and contract in an axial direction, thereby reducing the aforementioned stress level and fatigue cracking.

It is also known in the heat exchanger art, wherein, a body of pervious material is employed in a single pass unit, to provide for expansion and contraction of the heat exchanger tubes while the end plate at the outlet end of the tubes is held in a fixed position, as for example, by bolting. In such a unit the tube bundle "floats" at one end of the shell and, being a single pass unit does not employ a return water box.

The concept of the present invention may be employed in heat exchangers of any desired shape, but is particularly adapted to tubular heat exchangers. As is known in the art, the use of heat exchangers of a tubular configuration is highly advantageous in certain environments wherein it is desired that the heat exchange take place wholly within the exchanger. The tubular heat exchangers commonly in use in such an environment are of the type known in the art as "shell and tube," wherein a plurality of tubular elements conveying one heat exchange medium are arranged within a shell through which is circulating another heat exchange medium with or without the use of baffles to direct the flow, which is substantially axial along the tubes.

The concept of the instant invention provides for a heat exchanger employing a body of pervious material

thus providing for high rates of heat transfer, and wherein fatigue cracking caused by cyclic operation of the heat exchanger is eliminated. In this concept the heat exchanger core is free to expand and contract in accordance with thermal stresses caused by differences in the operating temperatures. Thus, the tubes of the core are free to move independently of the surrounding shell and thus working of the tubes due to differential thermal expansion and contraction of the shell does not occur.

It will be understood that various combinations of materials may be utilized in forming the heat exchanger according to the instant invention; and accordingly the solid portions and pervious body and the solid portions of the exchanger may be comprised of different compositions. For example, both the pervious body and other portions of the heat exchanger may be formed of the same stainless steels, coppers, brasses, carbon steels, aluminums or various combinations thereof. As will be evident the ultimate use of the resultant structures determines the specific combination of the alloys to be employed.

It is accordingly an object of this invention to provide a heat exchanger which is highly compact and yet capable of high efficiency and low pressure drop.

It is a further object of this invention to provide such a heat exchanger having a body of pervious material therein.

It is a still further object of the present invention to provide such a heat exchanger comprising a tubular member having a plurality of inner tubular members metallically bonded in a body of pervious material.

It is a still further object of the present invention to provide such an exchanger wherein the core is free to expand and contract and thus thermal stress fatigue failures are substantially eliminated.

Additional objects and advantages will become apparent to those skilled in the art from a consideration of the details of several specific embodiments illustrated in the drawings, in which:

FIG. **1** is a longitudinal cross-section of a heat exchanger employing the concept of this invention.

FIG. **2** is an axial cross section of the heat exchanger of FIG. **1**, taken along lines **2 — 2** thereof.

FIG. **3** is a longitudinal cross section of an alternative embodiment of the present invention.

FIGS. **4-8** are longitudinal cross-sections showing additional embodiments of the instant invention.

The first embodiment of the heat exchanger according to this invention is shown in FIG. **1** and is designated generally by numeral **10.** A first heat exchange medium, for example, the medium to be employed in heating or cooling, is introduced into the heat exchanger **10** through an inlet as shown by arrow **12** flows through the tubes in the pervious body **14,** and exits from an outlet in the direction of arrow **16.** The second heat exchange medium, for example the medium to be cooled or heated, enters the heat exchanger **10** through any suitable fitting in the direction of arrow **18,** is circulated through the pervious body and exits through a suitable fitting in the direction of arrow **20.** It will be obvious that any desired media might be employed in the instant heat exchanger, for example the medium introduced at **12** may be water and that at **18** may be oil. It is preferred that a sealing assembly comprised of an O-ring **35** and a retaining ring **37** be placed so as to surround the pervious body **14** so as to support the pervi-

ous body within the first conduit means and so as to direct the flow of the first heat transfer media.

A first, or inlet aperture, or water box **22** is provided with a baffle **24** so as to direct the incoming medium to only a portion of tubular elements **26.** Likewise, a second aperture **28** is provided as a collecting means to redirect the medium back through the remaining portion of tubes **26** to aperture **22.** Taken collectively the tubular elements and the first and second apertures may be referred to as the core. Space S is also provided to allow for expansion of the core.

Referring now to FIG. **2** of the drawings, it may be seen that the tubular elements are surrounded by and metallurgically bonded to pervious body **14.** The tubular elements **26** may be referred to collectively as the second or internal conduit means, and the shell **29** as the first conduit means.

The direction of flow of the heat exchange medium flowing through the second or internal, conduit means is shown by inlet **12** and outlet **16.**

Thus, the entering heat media enters through the inlet **12** to the first aperture **22** whence it flows through a portion of the tubular elements **26** to the second aperture **28** whence it is directed back through the tubular elements **26** to the first aperture **22** and the outlet **24.** By this arrangement only a portion of the tubular elements are used for flow of the medium to the second aperture and the remaining portion of the tubular elements serve to carry the medium back to the first or inlet aperture. This arrangement is commonly termed a two pass or return flow heat exchanger in the art. The baffle **24** is provided within the first aperture so that the entering medium is first directed only to the desired portion of the tubes.

As will be noted by FIG. **1** the second aperture or collecting means in this embodiment comprises two members **30** and **32** which are in opposing and interfitting relationship with each other. Naturally other suitable configurations may also be employed to provide a collection means for the heat exchange medium and to redirect the medium through the remaining portion of tubes to the outlet of the second conduit. It is also to be noted that the core is connected such as by brazing to the first conduit means, or shell, only at the first aperture and is therefore free to contract or expand independently of the surrounding shell.

The body of the pervious material **14** surrounds and fills the spaces between the tubular elements **26.** Naturally, the pervious material is not limited to any particular configuration as, for example, the porous material may surround only a portion of the tubular elements or may entirely fill the first conduit means around the tubular elements, depending upon any particular desired heat transfer relationship.

It may be seen that the tubular elements and the first and second apertures, comprising the core, are free to expand and contract since the core is attached to the first conduit only at the first aperture as shown by numeral **34.** If desired the core need not be joined at all to the shell, as shown in FIG. **3** which illustrates an alternative embodiment of the aperture **22** of FIG. **1** and in this concept the entire core is completely independent of the shell relative to expansion and contraction. Suitable sealing means, such as an O-ring **36,** positioned in retainer **38,** to seal the first heat exchange medium from the second is provided in this embodiment. Thus, during the thermal differences caused when thermal cycling occurs, the core need not expand and contract in accordance with the expansion and contraction of the shell or first conduit.

For example, in a typical heat exchanger not of the configuration of the present invention a steel shell may be employed and the tubes may be of copper. The thermal expansion co-efficient of steel is given as 6.2×10^{-6} $^{in.}$/in. $-^{\circ}F$ while that of copper is 9.2×10^{-6} $^{in.}$/in. $-^{\circ}F$ in the present example it is assumed that the ambient temperatures is 70°F the water flowing through the tubes is at 75°F and the oil is at an average temperature of 150°F.

If the water is not flowing then both the core and the shell will ultimately stabilize at 150°F. The steel shell will then expand in accordance with the following relationship, assuming that the shell and core length is 20 inches.

$$(6.2 \times 10^{-6}) \times 20 \times 75 = 9.3 \times 10^{-3} = 0.0093 \text{ inch}$$

Under the same conditions the core will expand in accordance with the following relationship:

$$(9.2 \times 10^{-6}) \times 20 \times 75 = 13.8 \times 10^{-3} = 0.0138 \text{ inch}$$

If the water is again caused to flow at a rate to achieve a temperature of 75°F the shell will remain at 150°F for a period of time which will then result in a difference of length of about 0.0093 inch between the core and the shell.

The stress level caused by the aforementioned differences in lengths may be calculated by the following general relationship wherein it is assumed that the difference is mainifested completely in one material and not in the other.

$d = PL/AE$ where

d = elongation of metal bar

P = load required for this elongation

L = length of bar

A = cross-sectional area of bar

E = modulus of elasticity for bar

Since P/A is stress, S, then $S = dE/L$

In accordance with the foregoing relationship the stresses are found to be that of 8,140 psi for copper and about 14,000 psi for the steel. Since the steel will not stretch under these conditions due to relatively high yield strength the stress is then essentially applied to the copper alone. Concentration factors may easily double the stress level which will then be considerably higher than the 5,000 to 12,000 psi yield strength for annealed deoxidized copper. Repeated applications of these stresses generally results in failure at the point of highest stress which is normally just behind the header side which contacts the first heat exchange medium.

In conventional shell and tube heat exchangers fatigue failure is not a significant problem since expansion and contraction will result in slight bowing of the tubes thus reducing the stress level to a considerable extent and generally below the yield strength of the metal. In addition tubes in the hard drawn state are usually employed which thereby have a higher yield strength and, as such, induced stresses do not always result in a stress above the yield strength and therefore fatigue cracking would not occur. In addition heavy headers are frequently employed which provide for a distribution of the stresses over a relatively large mass of header material and which likewise reduces the stress level to the point where fatigue cracking would not be expected to occur.

In a heat exchanger employing a body of pervious material substantially surrounding the tubes, however, a particular tube is not free to bow and thus reduce the stress level since it is restricted by the surrounding mass of pervious material. Thus, the fatigue cracking is much more apt to occur due to this restrictive movement of the tubes than would be expected in a heat exchanger not having such a pervious body.

Furthermore, in such a heat exchanger the pervious body is metallurgically bonded to the tubes by a heating operation and thus the essentially annealed tubes are in a soft condition. Thus, the yield strength is considerably lower than when in the hard condition and the tubes are much more apt to fatigue crack during thermal cycling.

In addition since the outer bank of tubes in this type of exchanger is spaced at a relatively greater distance from the inside surface of the shell than in a conventional exchanger not employing the concept of the instant exchanger, the moment of force exerted upon the tubes is thus greater, thereby increasing the chance of fatigue failure. These fatigue failures are more likely to occur in an exchanger employing a body of pervious material as in the instant invention than in a conventional type heat exchanger which does not employ the floating heat concept. That is, in such a heat exchanger the stress level at which fatigue cracking is likely to occur is lower than in a non-floating head type conventional exchanger.

The instant inveniton therefore provides a heat exchanger having a sintered metal matrix and in which the core is free to expand and contract thereby eliminating faigue failure.

Referring again to the drawings, FIGS. **4–8** show other further preferred embodiments of the present invention.

FIG. **4** shows a collecting means wherein both members **30** and **32** are in a cup shaped and interfitting relationship.

FIG. **5** shows a collecting means wherein a retainer having an O-ring **36** is positioned surrounding the tubes and brazed to the second aperture **28.** By this arrangement is provided a means of support for the tubular elements wherein the retainer **38** is likewise free to move in the direction caused by expansion or contraction. In this embodiment the retainer **38** has a passageway communicating from the shell side to the space between the second aperture or collecting means **28** and the end of the shell. By this arrangement pressure on the cup member **32** is substantially equalized since fluid under pressure is now present both within the collecting means and on the outside in the aforementioned spaces. This space naturally also serves as an area for expansion and contracting of the core and collecting means. Naturally, if desired, the retainer **38** need not be provided with a passageway if so desired.

FIG. **6** shows another embodiment of the present invention wherein the retainer **38** is positioned adjacent the second aperture in the spaces between the aperture **28** means and the end of the shell.

FIG. **7** shows a heavy closure **40** which need not be in a cup shape configuration, brazed to the cup member **30.**

FIG. **8** shows a single dome shaped member **42,** rather than the two members brazed together, which is brazed to a header **44** to form the collecting means.

Considering now one preferred method by which the instant heat exchanger may be produced, the tubes **26** may be positioned in apertures of the header or member **30** and the resulting seembly situated in an appropriate mold which comprises for example, wire mesh in a cylindrical form for forming the shape of the pervious body. Therefore, the particles of pervious body may be poured into the mold and sintered with provision having been made for leaving the desired voids. The assembly may then be inspected, and the openings of member **30** through which the tubes pass may be appropriately sealed if such a seal has not been accomplished by the preliminary joining process. The members may then be suitably secured within shell **10** and appropriately sealed. Fittings may be added at any stage of the manufacture, and any further end fittings added as needed.

The present invention thus provides for a heat exchanger for a sintered metal matrix and consequence high rate of transfer and wherein the core may expand and contract in accordance with thermal stress thereby eliminating fatigue cracking.

Although the several embodiments of the present invention shown herein depect a two pass configuration for conveying the second heat exchange medium naturally the present invention is also readily applicable to multiples of the two pass configuration, such as a four pass unit. In this type of unit the basic flow of the second heat exchange medium is merely doubled etc. by including additional baffling as may be readily understood.

This invention may be embodied in other forms or carried out in other ways without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered as in all respects illustrative and not restrictive the scope of the invention being indicated by the appended claims, and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

What is claimed is:

1. A heat exchange apparatus comprising:

A. a first conduit means having an inlet and an outlet for conveying a first heat exchange medium;

B. a second conduit means within said first conduit means, said second conduit means having an inlet and an outlet and having a plurality of spaced apart tubular elements having inlet and outlet ends to form a core for conveying a second heat exchange medium;

C. a body of pervious heat conductive material positioned within said first conduit means and in heat exchange relationship and metallically bonded with said second conduit means and at least substantially filling the spaces between said spaced apart tubular elements;

D. at least one first means communicating with said inlet of said second conduit means for directing said second heat exchange medium to a portion of said tubular elements to pass therethrough;

E. at least one second means for collecting said second heat exchange medium, said second means further directing said second heat exchange medium to the remaining portion of said tubular elements to pass therethrough to said first means and to said outlet of said second conduit means, said second conduit means being free to expand and contract in an axial direction within said first conduit means; and

F. sealing means to within the space between the exterior of the porous metal body and the interior of the first conduit means, with said sealing means being located so as to support said second conduit means, and positioned between the inlet and outlet of the first conduit means, whereby the first heat exchange medium flows through the pervious metal body and with said sealing means being free to move responsive to expansion and contraction of said second conduit means.

2. A heat exchange apparatus in accordance with claim **1** which includes at least one added means for supporting said second conduit means within said first conduit means, said added means being adjacent one end of said second conduit means

3. A heat exchange apparatus in accordance with claim **2** wherein said added support means comprises a ring member surrounding said tubular elements and said body of pervious material.

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