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(54) **PARALLEL FLOW HEAT EXCHANGERS INCORPORATING POROUS INSERTS**

PARALLELSTROMWÄRMETAUSCHER MIT PORÖSEN EINSÄTZEN

ECHANGEURS THERMIQUES A FLUX PARALLELE RENFERMANT DES ELEMENTS D'INSERTION POREUX

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Description

Background of the Invention

[0001] This invention relates generally to air conditioning, heat pump and refrigeration systems and, more particularly, to parallel flow evaporators thereof.

[0002] A definition of a so-called parallel flow heat exchanger is widely used in the air conditioning and refrigeration industry and designates a heat exchanger with a plurality of parallel passages, among which refrigerant is distributed and flown in the orientation generally substantially perpendicular to the refrigerant flow direction in the inlet and outlet manifolds. This definition is well adapted within the technical community and will be used throughout the text.

[0003] Refrigerant maldistribution in refrigerant system evaporators is a well-known phenomenon. It causes significant evaporator and overall system performance degradation over a wide range of operating conditions. Maldistribution of refrigerant may occur due to differences in flow impedances within evaporator channels, non-uniform airflow distribution over external heat transfer surfaces, improper heat exchanger orientation or poor manifold and distribution system design. Maldistribution is particularly pronounced in parallel flow evaporators due to their specific design with respect to refrigerant routing to each refrigerant circuit. Attempts to eliminate or reduce the effects of this phenomenon on the performance of parallel flow evaporators have been made with little or no success. The primary reasons for such failures have generally been related to complexity and inefficiency of the proposed technique or prohibitively high cost of the solution.

[0004] In recent years, parallel flow heat exchangers, and furnace-brazed aluminum heat exchangers in particular, have received much attention and interest, not just in the automotive field but also in the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry. The primary reasons for the employment of the parallel flow technology are related to its superior performance, high degree of compactness and enhanced resistance to corrosion. Parallel flow heat exchangers are now utilized in both condenser and evaporator applications for multiple products and system designs and configurations. The evaporator applications, although promising greater benefits and rewards, are more challenging and problematic. Refrigerant maldistribution is one of the primary concerns and obstacles for the implementation of this technology in the evaporator applications.

[0005] As know, refrigerant maldistribution in parallel flow heat exchangers occurs because of unequal pressure drop inside the channels and in the inlet and outlet manifolds, as well as poor manifold and distribution system design. In the manifolds, the difference in length of refrigerant paths, phase separation and gravity are the primary factors responsible for maldistribution. Inside the heat exchanger channels, variations in the heat transfer rate, airflow distribution, manufacturing tolerances, and gravity are the dominant factors. Furthermore, the recent trend of the heat exchanger performance enhancement promoted miniaturization of its channels (so-called minichannels and microchannels), which in turn negatively impacted refrigerant distribution. Since it is extremely difficult to control all these factors, many of the previous attempts to manage refrigerant distribution, especially in parallel flow evaporators, have failed.

[0006] In the refrigerant systems utilizing parallel flow heat exchangers, the inlet and outlet manifolds or headers (these terms will be used interchangeably throughout the text) usually have a conventional cylindrical shape. When the two-phase flow enters the header, the vapor phase is usually separated from the liquid phase. Since both phases flow independently, refrigerant maldistribution tends to occur.

[0007] If the two-phase flow enters the inlet manifold at a relatively high velocity, the liquid phase (droplets of liquid) is carried by the momentum of the flow further away from the manifold entrance to the remote portion of the header. Hence, the channels closest to the manifold entrance receive predominantly the vapor phase and the channels remote from the manifold entrance receive mostly the liquid phase. If, on the other hand, the velocity of the two-phase flow entering the manifold is low, there is not enough momentum to carry the liquid phase along the header. As a result, the liquid phase enters the channels closest to the inlet and the vapor phase proceeds to the most remote ones. Also, the liquid and vapor phases in the inlet manifold can be separated by the gravity forces, causing similar Maldistribution consequences. In either case, maldistribution phenomenon quickly surfaces and manifests itself in evaporator and overall system performance degradation.

[0008] Moreover, maldistribution phenomenon may cause the two-phase (zero superheat) conditions at the exit of some channels, promoting potential flooding at the compressor suction that may quickly translate into the compressor damage.

A microchannel heat exchanger as described in the preamble to claim 1 may be found in US 4,903,761.

Summary of the Invention

[0009] It is therefore an object of the present Invention to provide for a system and method which overcome the problems of the prior art described above.

The present invention provides a parallel flow minichannel or microchannel heat exchanger comprising: an inlet manifold extending longitudinally and having an inlet opening for conducting the flow of a fluid into said inlet manifold and a plurality of outlet openings for conducting the flow of fluid transversely from said inlet manifold; a plurality of channels, each having a channel entrance, aligned in substantially parallel relationship and fluidly connected to said plurality of outlet openings for conducting the flow of fluid from said Inlet manifold; and an outlet manifold fluidly connected to said plurality of said channels for receiving the flow of fluid therefrom; wherein said heat exchanger contains at least one porous member positioned within the flow path of said heat exchanger; characterised in that said porous member is positioned at said channel entrance, whereby said heat exchanger exhibits a significant reduction of flow maldistribution among said plurality of channels.

[0010] The objective of the present invention is to introduce a pressure drop control for the parallel flow (microchannel or minichannel) evaporator that will essentially equalize pressure drop through the heat exchanger circuits and therefore eliminate refrigerant maldistribution and the problems associated with it.

Further, it is the objective of the present invention to provide refrigerant expansion at the entrance of each channel, thus eliminating a predominantly two-phase flow in the inlet manifold, which is one of the main causes for refrigerant maldistribution. It has been found that the introduction of a porous media inserted in each parallel flow evaporator channel, or at the entrance of each parallel flow evaporator channel, accomplishes these objectives. For instance, these porous media inserts can be brazed in each channel during furnace brazing of the entire heat exchanger, chemically bonded or mechanically fixed in place. Furthermore, these inserts can be used as primary (and the only) expansion devices for low-cost applications or as secondary expansion devices, in case precise superheat control is required and a thermostatic expansion valve (TXV) or an electronic expansion valve (EXV) is employed as a primary expansion device.

[0011] Any suitable porous insert which accomplishes the above objectives may be used. Suitable and inexpensive porous inserts may be made of sintered metal, compressed metal, such as steel wool, specialty designed porous ceramics, etc. When inexpensive porous media insert is placed in each channel of the parallel flow evaporator, or at the entrance of each parallel flow evaporator channel, it represents a major resistance to the refrigerant flow within the evaporator. In such circumstances, the main pressure drop region will be across these inserts and the variations in the pressure drop in the channels or in the manifolds of the parallel flow evaporators will play a minor (insignificant) role. Further, since refrigerant expansion is taking place at the entrance to each channel, a predominantly single-phase liquid refrigerant is flown through the inlet manifold, especially in the case when the porous inserts are utilized as the primary and the only expansion devices. Hence, uniform refrigerant distribution is achieved, evaporator and system performance is enhanced and, at the same time, precise superheat control is not lost (whenever required). Furthermore, low extra cost for the proposed method makes this invention very attractive.

Brief Description of the Drawings

[0012] For a further understanding of the objects of the invention, reference will be made to the following detailed description of the invention which is to be read in connection with the accompanying drawing, where:

[0013] Fig. 1 is a schematic illustration of a parallel flow heat exchanger in accordance with the prior art.

[0014] Fig. 2 is a partial side sectional view of one embodiment of the present invention.

[0015] Fig. 3 is an end view of a porous insert positioned at the entrance to a channel of the present invention.

[0016] Fig. 4 is a perspective view of the porous insert illustrated in Fig. 3.

[0017] Fig. 5a is a side sectional view illustrating a further embodiment of the present invention.

[0018] Fig. 5b is a side sectional view illustrating yet a further embodiment of the present invention.

[0019] Fig. 6 is an end view of a plurality of channels in one embodiment of the invention.

[0020] Fig. 7a is a perspective view which illustrates a porous cap embodiment.

[0021] Fig. 7b is a perspective view which illustrates a second porous cap embodiment.

Description of the Preferred Embodiment

[0022] Referring now to Fig. 1, a parallel flow (minichannel or microchannel) heat exchanger 10 is shown which includes an inlet header or manifold 12, an outlet header or manifold 14 and a plurality of parallel disposed channels 16 fluidly interconnecting the inlet manifold 12 to the outlet manifold 14. Typically, the inlet and outlet headers 12 and 14 are cylindrical in shape, and the channels 16 are tubes (or extrusions) of flattened or round cross-section. Channels 16 normally have a plurality of internal and external heat transfer enhancement elements, such as fins. For instance, external fins 18, uniformly disposed therebetween for the enhancement of the heat exchange process and structural rigidity, are typically furnace-brazed. Channels 16 may have internal heat transfer enhancements and structural elements as well.

[0023] In operation, refrigerant flows into the inlet opening 20 and into the internal cavity 22 of the inlet header 12. From the internal cavity 22, the refrigerant, in the form of a liquid, a vapor or a mixture of liquid and vapor (the most typical scenario in the case of an evaporator with an expansion device located upstream) enters the channel openings 24 to pass through the channels 16 to the internal cavity 26 of the outlet header 14. From there, the refrigerant, which is now usually in the form of a vapor, in the case of evaporator applications, flows out of the outlet opening 28 and then to the compressor (not shown). Externally to the channels 18, air is circulated preferably uniformly over the channels 16 and associated fins 18 by an air-moving device, such as fan (not shown), so that heat transfer interaction occurs between the air flowing outside the channels and refrigerant within the channels.

[0024] According to one embodiment of the present invention, a porous insert 30 is inserted at the entrance of each channel 16. When the channels 16 have internal structural elements such as support members 16a (Fig. 3), usually included for structural rigidity and/or heat transfer enhancement purposes, the porous inserts 30 incorporate slots 32 to accommodate the support members 16a when In position at the channel entrance (See Fig. 4). Further, in case a various degree of expansion and/or hydraulic impedance are desired to be provided by the inserts 30 or 32, for Instance, to counter-balance other abovementioned factors affecting refrigerant distribution amongst the channels 18, characteristics such as porosity values or geometric dimensions (insert depth, insertion depth, etc.) of the inserts can be altered to achieved the desired result for each channel 16.

[0025] Fig. 5a Illustrates another embodiment in which all the entrances to the channels 16 are covered by a single porous member 34 positioned within a manifold 40. Further, a support member 36 may be used to assist in setting up a relative position of the porous member 34 and the channels 16 within the manifold 40. It should be noted that an assembly of the porous member 34 and support member 36 can be manufactured from and combined in a single member made from porous material.

[0026] Fig. 5b is a further embodiment of the structure of Fig. 5a in which the porous member is a composite of two different porous materials 34 and 34a. Obviously, a number of composite materials within the porous member can be more than two.

[0027] Fig. 6 illustrates a side view of Fig. 5a.

[0028] Fig. 7a illustrates an elongated porous member 34c which caps the ends of multiple channels 16.

[0029] Fig. 7b a modification of the structure of Fig. 7a in which the porous member 34d Is accurate in shape and caps the ends of the channels 16. The shape of the porous member 34d can be of any suitable configuration, rather than a rectangular in cross-section. Further, the porous member 34d is preferably positioned within the manifold 40 in such way that there is a gap between the inner wall of the manifold 40 and the porous member 34a allowing for more uniform refrigerant distribution prior to entering the porous member 34d and channels 16.

[0030] It should be understood that any type of porous member and/or material which accomplishes the obj ectives of the present invention may be used. Similarly, as illustrated by Figs. 2-7, any design or configuration which accomplishes the objectives of the invention may be employed in the use of the present invention.

[0031] Also, it has to be noted that the porous inserts can be used in the condenser and evaporator applications within intermediate manifolds as well. For instance, if a heat exchanger has more than one refrigerant pass, an intermediate manifold (between inlet and outlet manifolds) is incorporated in the heat exchanger design. In the intermediate manifold, refrigerant is typically in a two-phase state, and such heat exchanger configurations can similarly benefit from the present invention by incorporating the porous inserts into such intermediate manifolds. Further, the porous inserts can be placed into an inlet manifold of the condenser and an outlet manifold of the evaporator for providing only hydraulic resistance uniformity and pressure drop control and with less effect on overall heat exchanger performance.

[0032] Since, for particular applications, the various factors that cause the maldistribution of refrigerant to the channels are generally known at the design stage, the inventors have found it feasible to introduce the design features that will counter-balance them in order to eliminate the detrimental effects on the evaporator and overall system performance as well as potential compressor flooding and damage. For instance, in many cases, it is generally known whether the refrigerant flows into the inlet manifold at a high or low velocity and how the maldistribution phenomenon is affected by the velocity values. A person of ordinarily skill in the art will recognize how to apply the teachings of this invention to other system characteristics.

[0033] While the present invention has been particularly shown and described with reference to the preferred embodiments as illustrated in the drawing, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the scope of the invention as defined by the claims.

Claims

1. A parallel flow minichannel or microchannel heat exchanger (10) comprising:

an inlet manifold (12) extending longitudinally and having an inlet opening (20) for conducting the flow of a fluid into said inlet manifold and a plurality of outlet openings (28) for conducting the flow of fluid transversely from said inlet manifold;

a plurality of channels (16), each having a channel entrance, aligned in substantially parallel relationship and fluidly connected to said plurality of outlet openings for conducting the flow of fluid from said inlet manifold; and

an outlet manifold (14) fluidly connected to said plurality of said channels for receiving the flow of fluid therefrom;

wherein said heat exchanger contains at least one porous member (34) positioned within the flow path of said heat exchanger;

characterised in that

said porous member is positioned at said channel entrance, whereby said heat exchanger exhibits a significant reduction of flow maldistribution among said plurality of channels.

2. A parallel flow minichannel or microchannel heat exchanger as set forth in claim 1, wherein said porous member is designed to provide for at least one of an expansion control and a pressure drop control in the system.

3. A parallel flow heat exchanger as set forth in claim 1 or 2 wherein said heat exchanger is an evaporator.

4. A parallel flow heat exchanger as set forth in claim 1 or 2 wherein said heat exchanger is a condenser.

5. The heat exchanger of claim 1 or 2 wherein the porous member functions as a primary expansion device.

6. The heat exchanger of claim 1 or 2 wherein the porous member functions as a secondary expansion device.

7. A parallel flow heat exchanger as set forth in any one of claims 1 to 6 wherein said porous member is in the form of an insert positioned in at least one channel.

8. A parallel flow heat exchanger of claim 7 wherein the said porous member Is positioned adjacent said channel entrance.

9. A parallel flow heat exchanger of claim 7 wherein said porous member is positioned inside said channel.

10. A parallel flow heat exchanger as set forth in any one of claims 1 to 6, wherein said porous member is positioned in the inlet manifold or in the outlet manifold.

11. The parallel flow heat exchanger of claim 10 wherein said member is positioned longitudinally along the manifold.

12. The parallel flow heat exchanger of claim 10 or 11 wherein there is a gap between said member and the manifold inner wall surface.

13. The parallel flow heat exchanger of claim 10, 11 or 12 wherein said member cross-section is non-rectangular.

14. The parallel flow heat exchanger of claim 13 wherein said member cross-section is a portion of a circle.

15. The parallel flow heat exchanger of any preceding claim wherein said member is made from a material selected from the group consisting of a metal and a ceramic.

16. The parallel flow heat exchanger of claim 15 wherein said member is made from a material selected from the group consisting of sintered metal, compressed metal, metal wool or metal wire.

17. The parallel flow heat exchanger of any preceding claim wherein said member is a composite of at least two different members.

18. The parallel flow heat exchanger of any preceding claim wherein sald members are of variable characteristics between at least two channels.

19. The parallel flow heat exchanger of claim 18 wherein the variable characteristics depend upon at least one of porosity, depth, insertion depth, and material.

Patentansprüche

1. Gleichstrom-Minikanal- oder -Mikrokanal-Wärmeübertrager (10), umfassend:

   ein Einlasssammelrohr (12), das längs verläuft und eine Einlassöffnung (20) zum Leiten des Stromes eines Fluids in das Einlasssammelrohr und mehrere Auslassöffnungen (28) zum Leiten des Fluidstromes quer vom Einlasssammelrohr aufweist,
   mehrere Kanäle (16) mit jeweils einem Kanaleingang, die in im Wesentlichen paralleler Beziehung ausgerichtet sind und in Fluidverbindung mit den mehreren Auslassöffnungen stehen, um den Fluidstrom vom Einlasssammelrohr zu leiten, und
   ein Auslasssammelrohr (14), das in Fluidverbindung mit den mehreren Kanälen steht, um den Fluidstrom aus diesen aufzunehmen,
   wobei der Wärmeübertrager mindestens ein poröses Element (34) enthält, das im Strömungsweg des Wärmeübertragers angeordnet ist,
   dadurch gekennzeichnet, dass
   das poröse Element an dem Kanaleingang positioniert ist, wodurch der Wärmeübertrager eine deutliche Verringerung einer mangelhaften Strömungsverteilung unter den mehreren Kanälen aufweist.

2. Gleichstrom-Minikanal- oder -Mikrokanal-Wärmeübertrager nach Anspruch 1, wobei das poröse Element dafür ausgebildet ist, für eine Ausdehnungssteuerung und/oder eine Druckabfallsteuerung in dem System zu sorgen.

3. Gleichstrom-Wärmeübertrager nach Anspruch 1 oder 2, wobei der Wärmeübertrager ein Verdampfer ist.

4. Gleichstrom-Wärmeübertrager nach Anspruch 1

oder 2, wobei der Wärmeübertrager ein Kondensator ist.

5. Gleichstrom-Wärmeübertrager nach Anspruch 1 oder 2, wobei das poröse Element als eine primäre Ausdehnungsvorrichtung dient.

6. Gleichstrom-Wärmeübertrager nach Anspruch 1 oder 2, wobei das poröse Element als eine sekundäre Ausdehnungsvorrichtung dient.

7. Gleichstrom-Wärmeübertrager nach einem der Ansprüche 1 bis 6, wobei das poröse Element die Form eines Einsatzes hat, der in mindestens einem Kanal positioniert ist.

8. Gleichstrom-Wärmeübertrager nach Anspruch 7, wobei das poröse Element an den Kanaleingang angrenzend positioniert ist.

9. Gleichstrom-Wärmeübertrager nach Anspruch 7, wobei das poröse Element in dem Kanal positioniert ist.

10. Gleichstrom-Wärmeübertrager nach einem der Ansprüche 1 bis 6, wobei das poröse Element im Einlasssammelrohr oder im Auslasssammelrohr positioniert ist.

11. Gleichstrom-Wärmeübertrager nach Anspruch 10, wobei das Element längs entlang dem Sammelrohr positioniert ist.

12. Gleichstrom-Wärmeübertrager nach Anspruch 10 oder 11, wobei ein Zwischenraum zwischen dem Element und der Innenwandoberfläche des Sammelrohrs besteht.

13. Gleichstrom-Wärmeübertrager nach Anspruch 10, 11 oder 12, wobei der Querschnitt des Elements nicht rechteckig ist.

14. Gleichstrom-Wärmeübertrager nach Anspruch 13, wobei der Querschnitt des Elements ein Kreisabschnitt ist.

15. Gleichstrom-Wärmeübertrager nach einem der vorhergehenden Ansprüche, wobei das Element aus einem Material besteht, das aus der Gruppe ausgewählt ist, die aus einem Metall und einer Keramik besteht.

16. Gleichstrom-Wärmeübertrager nach Anspruch 15, wobei das Element aus einem Material besteht, das aus der Gruppe ausgewählt ist, die aus gesintertem Metall, Pressmetall, Metallwolle oder Metalldraht besteht.

17. Gleichstrom-Wärmeübertrager nach einem der vorhergehenden Ansprüche, wobei das Element ein Verbund aus mindestens zwei verschiedenen Elementen ist.

18. Gleichstrom-Wärmeübertrager nach einem der vorhergehenden Ansprüche, wobei die Elemente mindestens zweier verschiedener Kanäle unterschiedliche Charakteristiken aufweisen.

19. Gleichstrom-Wärmeübertrager nach Anspruch 18, wobei die unterschiedlichen Charakteristiken von mindestens einem der Folgenden abhängen: Porosität, Tiefe, Einsatztiefe und Material.

Revendications

1. Échangeur de chaleur à minicanaux ou microcanaux et à flux parallèles (10) comprenant :

> un collecteur d'entrée (12) s'étendant longitudinalement et ayant une ouverture d'entrée (20) pour acheminer le flux d'un fluide dans ledit collecteur d'entrée et une pluralité d'ouvertures de sortie (28) pour acheminer le flux de fluide transversalement depuis ledit collecteur d'entrée ;
> une pluralité de canaux (16), chacun ayant une entrée de canal, alignés sensiblement selon un schéma parallèle et raccordés selon une communication fluide avec ladite pluralité d'ouvertures de sortie pour acheminer le flux de fluide depuis ledit collecteur d'entrée ; et
> un collecteur de sortie (14) raccordé selon une communication fluide avec ladite pluralité desdits canaux pour en recevoir le flux de fluide ;
> dans lequel ledit échangeur de chaleur contient au moins un élément poreux (34) positionné sur la trajectoire d'écoulement dudit échangeur de chaleur ;
> **caractérisé en ce que** :
>
> > ledit élément poreux est positionné dans ladite entrée de canal, si bien que ledit échangeur de chaleur présente une réduction sensible du flux mal distribué parmi ladite pluralité de canaux.

2. Échangeur de chaleur à minicanaux ou microcanaux à flux parallèles selon la revendication 1, dans lequel ledit élément poreux est conçu pour fournir au moins l'un d'un contrôle de dilatation et d'un contrôle de chute de pression dans le système.

3. Échangeur de chaleur à flux parallèles selon la revendication 1 ou la revendication 2, dans lequel ledit échangeur de chaleur est un évaporateur.

4. Échangeur de chaleur à flux parallèles selon la revendication 1 ou la revendication 2, dans lequel ledit échangeur de chaleur est un condensateur.

5. Échangeur de chaleur selon la revendication 1 ou la revendication 2, dans lequel l'élément poreux fonctionne comme dispositif de dilatation primaire.

6. Échangeur de chaleur selon la revendication 1 ou la revendication 2, dans lequel l'élément poreux fonctionne comme dispositif de dilatation secondaire.

7. Échangeur de chaleur à flux parallèles selon l'une quelconque des revendications 1 à 6, dans lequel ledit élément poreux se présente sous la forme d'un insert positionné dans au moins un canal.

8. Échangeur de chaleur à flux parallèles selon la revendication 7, dans lequel ledit élément poreux est positionné à côté de ladite entrée de canal.

9. Échangeur de chaleur à flux parallèles selon la revendication 7, dans lequel ledit élément poreux est positionné à l'intérieur dudit canal.

10. Échangeur de chaleur à flux parallèles selon l'une quelconque des revendications 1 à 6, dans lequel ledit élément poreux est positionné dans le collecteur d'entrée ou dans le collecteur de sortie.

11. Échangeur de chaleur à flux parallèles selon la revendication 10, dans lequel ledit élément est positionné longitudinalement le long du collecteur.

12. Échangeur de chaleur à flux parallèles selon la revendication 10 ou 11, dans lequel se trouve un espace entre ledit élément et ladite surface de paroi interne du collecteur.

13. Échangeur de chaleur à flux parallèles selon la revendication 10, 11 ou 12, dans lequel la section transversale dudit élément n'est pas rectangulaire.

14. Échangeur de chaleur à flux parallèles selon la revendication 13, dans lequel la section transversale dudit élément est une partie d'un cercle.

15. Échangeur de chaleur à flux parallèles selon l'une quelconque des revendications précédentes, dans lequel ledit élément est constitué d'un matériau choisi dans le groupe formé d'un métal et d'une céramique.

16. Échangeur de chaleur à flux parallèles selon la revendication 15, dans lequel ledit élément est constitué d'un matériau choisi dans le groupe constitué d'un métal fritté, d'un métal comprimé, d'une laine métallique ou d'un fil métallique.

17. Échangeur de chaleur à flux parallèles selon l'une quelconque des revendications précédentes, dans lequel ledit élément est un composite d'au moins deux éléments différents.

18. Échangeur de chaleur à flux parallèles selon l'une quelconque des revendications précédentes, dans lequel lesdits éléments ont des caractéristiques variables entre au moins deux canaux.

19. Échangeur de chaleur à flux parallèles selon la revendication 18, dans lequel les caractéristiques variables dépendent d'au moins une caractéristique choisie parmi la porosité, la profondeur, la profondeur d'insertion et le matériau.

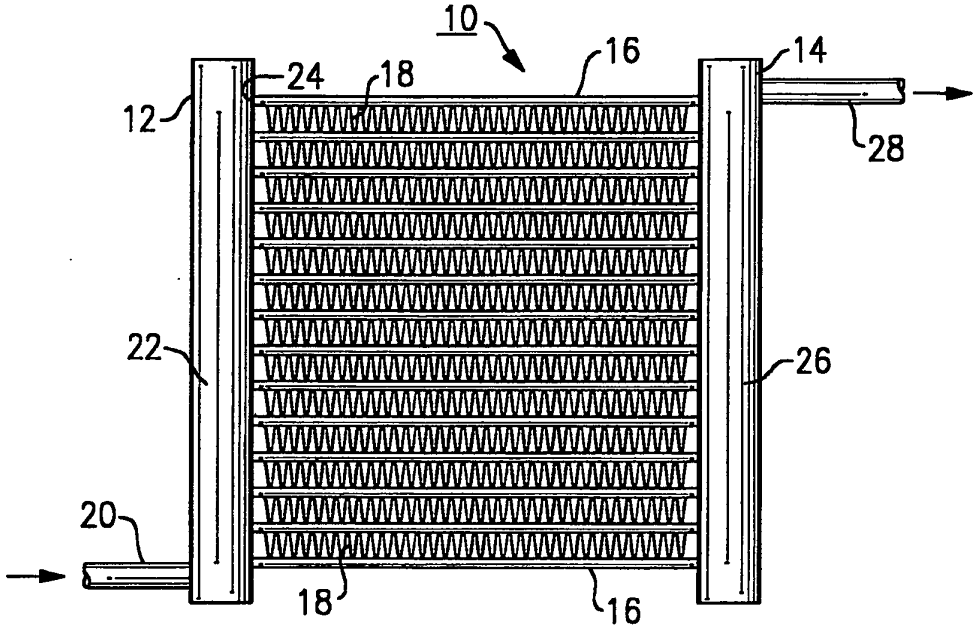

FIG.1
Prior Art

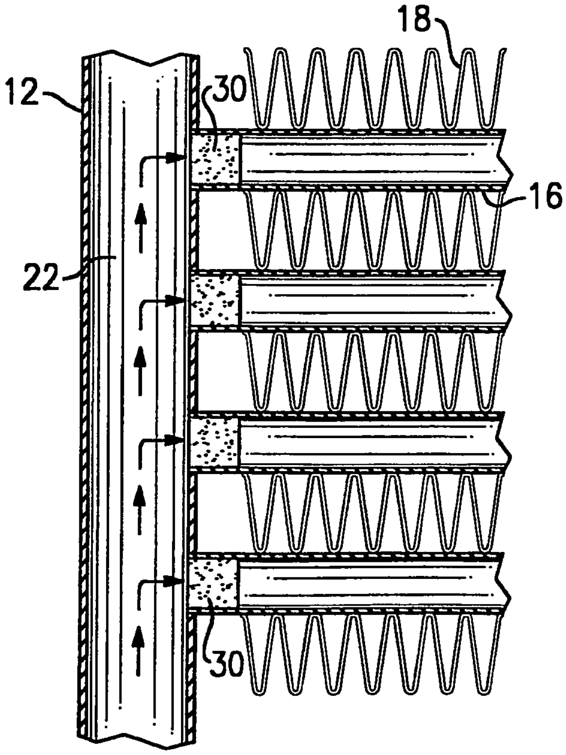

FIG.2

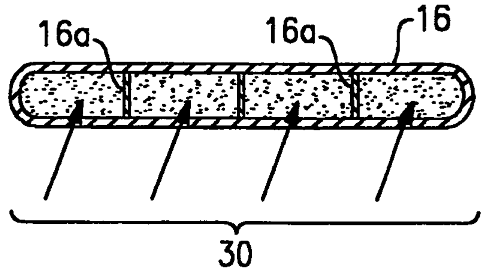

FIG.3

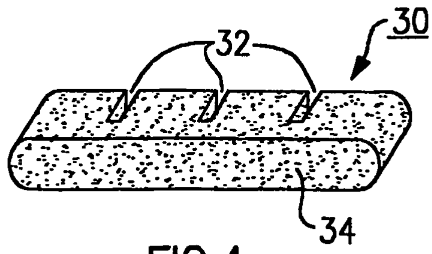

FIG.4

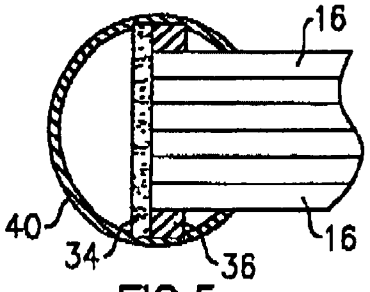

FIG.5a

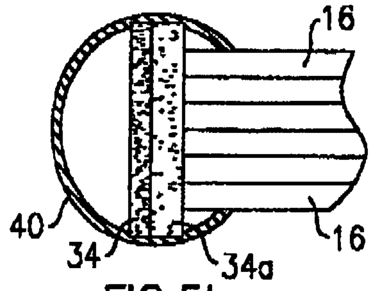

FIG.5b

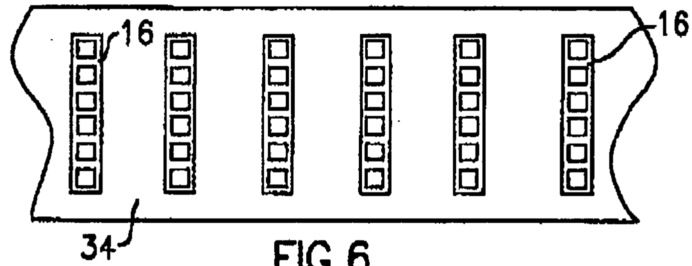

FIG.6

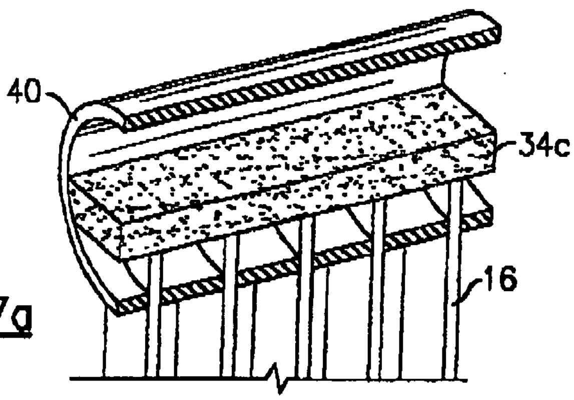

FIG.7a

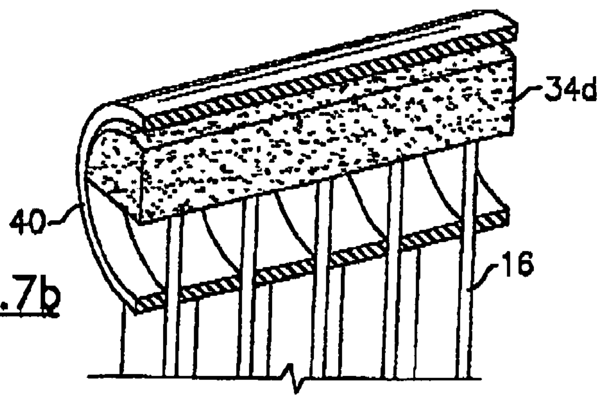

FIG.7b

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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