

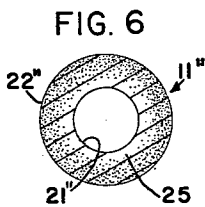
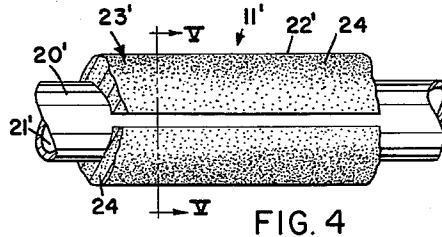
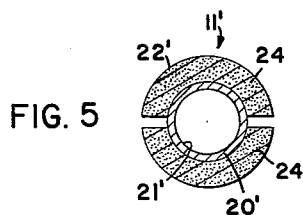
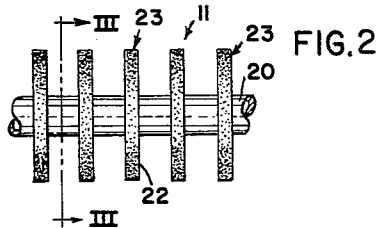
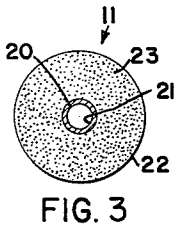
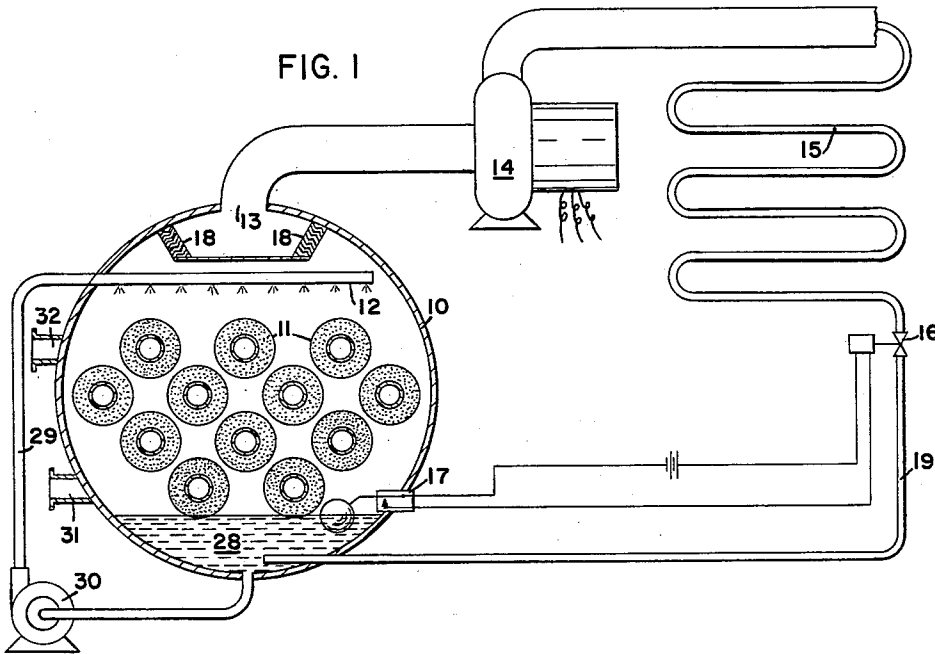
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HEAT EXCHANGE APPARATUS OF THE EVAPORATIVE TYPE

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HEAT EXCHANGE APPARATUS OF THE EVAPORATIVE TYPE

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9 Claims. (Cl. 62-512)

This invention relates to heat exchange apparatus and more particularly to an improved heat exchange tube and an improved heat exchanger of the evaporative type.

Heat exchangers of the type herein described are adapted for use in the evaporation or cooling unit of a centrifugal refrigeration system, though other applications of this invention will become readily apparent to those skilled in the heat exchange art. In such systems, it is frequent practice to dispose a plurality of heat exchange tubes in an outer shell and to connect the heat exchange tubes to form a circuit for the passage through their interior of a heat exchange fluid which is to be cooled. Frequently, heat exchangers of this type employ an extended heat transfer surface, such as fins, on the exterior of the heat exchange tubes to improve heat transfer with an exterior heat exchange medium. In order to promote heat exchange, it is also a frequent practice to maintain the exterior surfaces of the heat exchange tubes in a wetted condition by spraying them with the exterior heat exchange medium which is in a liquid state. Heat which is to be removed from the interior heat exchange fluid is conducted through the walls of the heat exchange tube and absorbed by the heat exchange liquid on the surface of the tubes causing the liquid to vaporize. Since a substantial quantity of heat is required to vaporize a liquid material, it is apparent that very good heat transfer capacity and rate of heat transfer may be obtained by this means. Heat exchangers of this type which depend largely upon vaporization of a liquid on the exterior surface by either evaporation or boiling are referred to herein as evaporative heat exchangers.

However, for an evaporative heat exchanger to function at maximum efficiency and thereby to secure the benefit of its very excellent theoretical heat exchange capabilities, it is necessary to maintain a relatively thin even film of liquid across the entire surface of the heat exchange tubes. On the other hand, because of the inherent surface tension of any liquid, particles of liquid from even a finely divided spray tend to coalesce into droplets on the exterior surface of an evaporative heat exchanger. Such action is highly disadvantageous because the area of heat exchange surface between the droplets is dry and consequently, evaporation of liquid cannot take place in these areas. Therefore, the effective area of evaporative heat transfer surface is substantially reduced over what it would be if a thin film of liquid were maintained over the entire surface of the heat exchange tube. On the other hand, the droplets constitute relatively thick layers of liquid which tend to insulate the surface of the heat exchange tubes and prevent as efficient heat transfer from taking place as would be the case if a uniformly thin film were maintained over the surface of the tubes.

In order to wet the surface of an evaporative heat exchange tube, it is common practice to use a fine spray of refrigerant or other liquid impinging on the surface of the tube in an attempt to keep its surface wet. In order to accomplish this objective satisfactorily, it becomes necessary to spray a substantial excess quantity of liquid over that which actually adheres to the surface of the heat exchange tube and evaporates therefrom. The designer of such a system is then faced with the problem of eliminating the entrained droplets of moisture which are present in the area surrounding the heat exchange tubes to pre-

vent undesirable carry over of the liquid to other parts of the machine. Consequently, in this and other types of evaporative heat exchangers it would be highly desirable to maintain a uniformly thin film or layer of liquid over substantially the entire surface of the heat exchange tubes. Not only does a thin film present a very large surface area for vaporization but also less quantity of liquid need be sprayed onto the tubes.

Another problem encountered in heat exchangers of the evaporative type is the low wettability of an impervious metal heat exchange surface. In order to obtain satisfactory wetting of an impervious surface such as a typical heat exchange tube, it is necessary to use a very finely divided spray for the purpose. However, a finely divided spray characteristically entrains a substantial quantity of unvaporized liquid droplets in the gaseous surrounding fluid (such as air) which are difficult to separate from the gaseous fluid. Consequently, entrainment elimination problems may be severe. However, with a highly wettable surface, the spray droplets need not be so fine or land so close to each other on the tube surface to get satisfactory wetting. Therefore, a less finely divided spray may be utilized, thereby, simplifying the elimination problem because the relatively large entrained droplets of such a spray are relatively easily eliminated from the surrounding vapor. In addition, greater wettability of the surface promotes the formation of a thin surface film of liquid over the surface of the heat exchange tube contributing to much more efficient heat transfer.

Accordingly, it is an object of this invention to provide an improved heat exchange tube having a surface which is adapted to promote evaporative heat exchange by being easily wetted with liquid in contact with a surface thereof.

It is a further object of this invention to provide an improved heat exchange tube for use in evaporative heat exchangers wherein the construction of the heat exchange tube is adapted to maintain a thin film of liquid heat exchange medium on one of its surfaces to promote efficient heat transfer.

It is a further object of this invention to provide an improved heat exchanger of the evaporative type.

These and other objects of this invention are achieved in the illustrated embodiments by providing heat exchange tubes having a relatively impervious interior surface with a relatively porous exterior surface. The porous exterior surface of the heat exchange tube is formed of a compacted metal powder having good thermal conductivity characteristics. In one embodiment of this invention, a heat exchange tube comprises fins of a compacted metal powder secured to the exterior of a tube; in another embodiment, a porous jacket of compacted metal powder extends partially around the exterior of a tube; and in a third embodiment of this invention, a heat exchange tube is constructed of compacted metal powder and has integral interior and exterior surfaces, one of which is porous and the other of which is impervious. Because of the porous nature of one of the surfaces of the heat exchange tubes in each of these embodiments, liquid which is sprayed or otherwise placed in contact with the porous surface is absorbed into the porous body of the heat exchange tube. As liquid evaporates from the porous surface of the tube, additional liquid is supplied by capillary action from the porous interior region of the body to the surface thereby maintaining the heat exchange surface wetted with a thin film of liquid at all times. Consequently, by the practice of this invention, the full advantages of evaporative heat transfer may be realized because dry areas in the heat exchange tube are substantially eliminated.

The details of preferred embodiments of this invention

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will become more apparent by reference to the following specification and attached drawings wherein:

FIGURE 1 is a schematic illustration of a refrigeration system including a cross-sectional view of a heat exchanger construction in accordance with this invention;

FIGURE 2 is a plan view of an improved heat exchange tube;

FIGURE 3 is a cross section taken substantially on line III—III of FIGURE 2;

FIGURE 4 is a plan view of a modified heat exchange tube partially broken away;

FIGURE 5 is a cross section taken substantially on line V—V of FIGURE 4; and

FIGURE 6 is a cross-sectional view of a further modified heat exchange tube constructed in accordance with this invention.

Referring particularly to the drawings wherein like reference numerals indicate corresponding portions throughout, there is shown in FIGURE 1 a schematic view of a centrifugal refrigeration system employing an evaporative heat exchanger embodying the instant invention. An outer shell 10 has disposed therein a plurality of elongated hollow heat exchange tubes 11 of a type which will presently be described and which may be connected at their ends by a header (not shown) to pass a fluid through them. A spray system 12 is located above heat exchange tubes 11 for the purpose of discharging a spray over the surface of the heat exchange tubes. An outlet 13 in the top shell 10 having entrainment eliminators 18 thereabout, is connected by a conduit to the inlet of centrifugal compressor 14. The outlet or discharge of centrifugal compressor 14 is connected to condenser 15. Liquid line 19 communicates the outlet of condenser 15 with sump 28 in the bottom of shell 10 through a control or expansion valve 16 which is placed in the line. An electric float control 17 may be provided, if desired, to control the operation of valve 16 in accordance with a desired liquid level in shell 10; other types of refrigerant controls may, of course, be alternatively or additionally employed if desired. Recirculation pump 30 recirculates refrigerant from sump 28 to spray system 12 through recirculation line 29.

In operation, vaporized liquid refrigerant is withdrawn from shell 10 through outlet 13 and entrainment eliminators 18 by compressor 14 and after being compressed, the refrigerant vapor is condensed to a liquid by condenser 15. Liquid refrigerant from condenser 15 passes through valve 16 which may serve as an expansion valve and to throttle the flow of liquid refrigerant to the sump 28. Spray system 12 discharges a spray of a volatile liquid refrigerant first heat exchange medium over the surface of heat exchange tubes 11 and the excess refrigerant accumulates in the lower portion of shell 10 which forms a sump 28. The interior shell 10 is previously purged of non-condensable gases and since a relatively low pressure exists therein by reason of the withdrawing action of compressor 14, refrigerant liquid adhering to the surfaces of heat exchange tubes 11 is vaporized from their surface by evaporation or boiling depending on the temperature difference between the tube surface and the vapor within shell 10.

A second heat exchange fluid flows through the interior of tubes 11 and is cooled by the removal of heat therefrom due to the vaporization of liquid refrigerant from the surfaces of the tubes. Suitable means, such as conduits 32, 31, are provided to pass the second heat exchange fluid to additional heat exchangers in the area to be cooled.

As the liquid refrigerant vaporizes, the heat of vaporization which is required to be added to the liquid in order to vaporize it, is removed from the second heat exchange fluid flowing through the interior of the heat exchange tubes by conduction of the heat through the walls of the heat exchange tubes. Since heat is removed from the

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second heat exchange fluid in the heat exchange tubes, that fluid is thereby cooled. The result is a net transfer of heat from the second heat exchange fluid to the first heat exchange medium which in the case illustrated is a refrigerant. The second heat exchange fluid may then be passed to the additional heat exchangers (not shown) in the area to be conditioned to maintain the desired temperature therein.

A typical heat exchange tube 11 is shown in FIGURE 2. The heat exchange tube may comprise an inner pipe 20 of relatively impervious material having a relatively high thermal conductivity. For example, pipe 20 may desirably be made of copper or aluminum. Disposed on the exterior of pipe 20 in close contact therewith are a plurality of fins 23 made of a relatively porous material such as compacted metal powder. It is desirable that the material of fins 23 likewise have high thermal conductivity and compacted powdered dendritic copper is a particularly advantageous material of which to make fins 23.

As used in this application, the term "porous" refers to the characteristic of a body having a large number of minute internal voids of capillary size. On at least one of the exposed surfaces and preferably all of the exposed surfaces of the body, the pores form surface interstices. The internal pores of the body are substantially in communication with each other and with the surface interstices. Consequently, a porous body, in the sense that the term is used herein is capable of absorbing a substantial quantity of liquid in contact with an interstitial surface thereof by capillary action. Consequently, a porous surface of a body as used herein may be thought of as a surface having a large number of surface interstices formed by and in communication with a large number of internal pores of capillary size such that liquid in contact with the porous surface is absorbed into the interior of the body. Conversely, if liquid is removed from the surface of the body, as by evaporation, additional liquid is caused to flow from the porous interior of the body to its surface by capillary action thereby replenishing and maintaining a surface film of liquid. This action continuously maintains a relatively thin film of liquid on the surface of the body until the supply of liquid in its interior pores is exhausted.

However, the process which is employed to compact the metal fins, jackets or tubes of this invention may be any of the known techniques for handling powdered metals providing the resulting compact remains porous. Fins 23 may be made by forming a mold of the desired shape of the fins, pouring a metal powder into the mold and applying sufficient pressure to compact the powder into a relatively rigid body or fin. Care must be taken during the compacting process to insure that the fin remains porous and that the pores are not sealed off from communication with each other or with a surface of the fin. Compaction of electrolytically produced dendritic copper powder at a pressure of about 800 p.s.i. in a suitable mold set in a hydraulic press has been found to give compacts having good absorptive properties. The compact may be thereafter sintered providing the sintering is not carried out to the point of sealing off the internal voids from communication with a desired surface of the compact.

As can be seen from consideration of FIGURES 2 and 3, heat exchange tube 11 comprises an elongated tubular body having a plurality of fins disposed on a relatively impervious hollow pipe 20. Fins 23 have outer surfaces 22 containing a large number of minute interstices in communication with the internally porous structure of the fins. Fin 23 may be secured to pipe 20 by brazing or soldering in order to obtain the most efficient heat transfer. Contacting surfaces on the pipe and the fin may be tinned if desired to facilitate brazing or soldering so that a good low resistance thermal bond is obtained. Alterna-

tively, fins 23 could be constructed as porous ridges integral with the surface of a pipe having a substantially nonporous interior surface. Consequently, heat exchange tube 11 has a relatively impervious interior surface 21 and a relatively porous exterior surface 22.

FIGURE 4 shows a modified embodiment of heat exchange tubes 11 wherein corresponding elements are designated by primed reference numerals. Heat exchange tube 11' has an elongated tubular body comprising a relatively impervious internal pipe 20' preferably of a good heat conducting material such as copper having impervious internal surface 21' and a relatively porous, elongated, axially extending jacket 23' disposed at least partially about its exterior surface. Jacket 23' is shown in FIGURE 5 to comprise a pair of generally semi-circular sleeves 24 and forms a coaxially extending porous exterior surface 22' about interior pipe 20'. Sleeves 24 may be extruded from a lightly compacted good heat conducting powdered metal such as copper and thereafter thinned and brazed or soldered on the outside of pipe 20' thereby minimizing thermal resistance between the jacket and the tube. Alternatively, jacket 23' may be formed by forming a porous ribbon or sheet of compacted metal powder which is subsequently bent to the desired shape to conform with the outer surface of pipe 20' and then secured thereto. While it is preferable that jacket 23' extend substantially completely around pipe 20', it is, of course, unnecessary that it do so and one or more spaced narrow segments or a porous axially extending metal rib may form the jacket if desired.

FIGURE 6 illustrates a further modified embodiment of heat exchange tubes 11. In this modification, the elongated tubular body of heat exchange tube 11' comprises a hollow integral pipe 25 having a relatively impervious interior surface portion 21'. A heat exchange tube of this nature may be formed by extruding a relatively rigid but lightly compacted pipe of metal powder of a good heat conducting material such as copper and either simultaneously or thereafter sintering the compact under conditions that will not result in eliminating or sealing off the internal voids from communication with the desired surface of the tube. Thereafter, an over-size swaging tool may be forced through the interior of the pipe to cold work the interior portion. If the pipe wall is relatively thin it may be desirable to support the exterior wall while swaging its interior. Whatever process is used to make the tube described should result in sealing off the surface interstices and internal voids which exist in the innermost region of the tube rendering the interior surface impervious while at the same time leaving the exterior surface portion of the tube relatively unaffected and hence porous.

It will be observed by forming heat exchange tubes in the manner so far described that each tube 11 comprises an axially elongated hollow body and has a relatively impervious interior surface for the flow of a heat exchange fluid in an external circuit (not shown). In addition, heat exchange tubes 11 have a relatively porous exterior surface comprising by way of example fins, jackets, or an integrally porous surface. Alternatively, the inner surface may be porous and the outer surface may be impervious for use in some types of heat exchangers. The porous surface may desirably be substantially axially co-extensive with the impervious surface.

In each instance, a substantial advantage of the described construction is realized because of the tendency of the porous surfaces to absorb liquid heat exchange medium such as refrigerant and continuously supply this heat exchange medium to a surface of the tube for evaporation thereby continuously maintaining a relatively thin film of liquid heat exchange medium on that surface of the tube. If a spray system of the type described is used and the flow of liquid therefrom is momentarily reduced or interrupted, no substantial change in heat

transfer characteristics will result until the liquid heat exchange medium absorbed by the porous surface has been exhausted by vaporization from the surface of the heat exchange tube.

In addition, a tube constructed in accordance with this invention is more easily wetted than nonporous surface tubes. This is true because a droplet of liquid falling on the porous exterior surface of a tube constructed in accordance with this invention will spread over a substantial area of the tube and wet the area instead of rolling down the side of the tube and dropping from the under-surface thereof. Similarly, if the interior surface of the tube is porous, as desirable in a falling film evaporator or absorber or in a direct expansion evaporator, wherein the liquid to be vaporized flows through the interior of the tube, a similar wetting of the entire inner surface can more easily take place due to capillary action of the liquid even though the flow of liquid is relatively small.

It will also be observed that an additional advantage is achieved by the construction herein described wherein a porous exterior surface of the heat exchange tubes tends to absorb liquid heat exchange medium by capillary action. Consequently, it is feasible to maintain the heat exchange tubes wetted by contacting a relatively small portion of their surface with liquid. For example, float control 17 may be adjusted so that the rows of heat exchange tubes in the lower portion of shell 10 as viewed in FIGURE 1 are partially submerged in liquid refrigerant. Under these conditions, those tubes furthest from the spray system 12 which are least likely to be well covered with sprayed refrigerant liquid may be maintained wet by capillary absorption of refrigerant which is collected in the lower or sump portion of shell 10 or dripped on them from the tubes above. An alternative wetting scheme would be to arrange heat exchange tubes 10 in a manner that they may be rotated so that their porous surfaces would continually dip into the accumulated liquid refrigerant to thereby absorb a substantial quantity of it. In addition, wicks could be attached to the porous exterior surface of the heat exchange tubes at one end while the other end of the wicks could dip into a reservoir of liquid refrigerant thereby conducting the liquid refrigerant heat exchange medium to an integral surface of the heat exchange tubes for subsequent evaporation therefrom. It will also be understood that the refrigerant liquid may be any desired noncorrosive volatile liquid such as water in the case of an evaporation condenser, for example.

It will be seen that by the practice of this invention, a simple and easily made heat transfer tube may be made which is capable of relatively large heat transfer capacity by reason of its adaptability to the maintenance of a thin layer or film of evaporating liquid from its surface. It will also be observed that the disadvantageous tendency of a sprayed liquid to coalesce into discrete droplets on the surface of a heat exchange tube while maintaining other regions of the surface of the tube relatively dry is overcome. These advantages are achieved without the necessity for enlarging the quantity of sprayed liquid and without imposing an unreasonable burden on eliminators should they be required by the particular application.

Heat exchangers of the type herein described are particularly useful in the evaporator, generator or absorber sections of an absorption refrigeration machine; an evaporative condenser; or the cooler section of a centrifugal refrigeration machine. The size, cost and weight of a machine employing heat exchange tubes of the type described is minimized because the superior heat transfer characteristics of such tubes make possible the use of fewer tubes or relatively shorter lengths of heat transfer tubes for a given application.

Other advantages and embodiments of this invention within the scope of the appended claims will occur to those skilled in the art. It will be understood that this invention is not confined to the illustrated or described

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embodiments but may be otherwise practiced within the scope of the following claims:

I claim:

1. A heat exchange apparatus comprising a shell, a plurality of connected heat exchange tubes within said shell, and means for discharging a refrigerant liquid directly onto an exterior surface of said heat exchange tubes, said tubes comprising a plurality of interiorly relatively impervious hollow heat exchange pipes having a porous exterior heat transfer surface thereon, said heat transfer surface comprising a preformed compacted porous metal body forming at least a portion of the exterior surface of said heat exchange tube, said porous metal body having a large number of surface interstices in the exterior surface thereof in direct contact with the discharged refrigerant, said surface interstices being in communication with minute internal pores of capillary size.
2. A heat exchange apparatus as defined in claim 1 wherein said heat transfer surfaces are integral with said heat exchange pipes.
3. A heat exchange apparatus as defined in claim 1 wherein said heat transfer surface comprises an elongated porous jacket.
4. A heat exchange tube for a heat exchanger of the type employing a wetted exterior surface heat exchange tube, comprising an axially elongated tubular metal body having a relatively impervious interior surface and another relatively porous exterior surface being exposed for direct contact with an ambient liquid, said porous exterior surface forming at least a portion of the exterior periphery of said heat exchange tube, said porous exterior surface comprising a compacted metal powder having a large number of surface interstices in communication with minute internal pores of capillary size.
5. A heat exchange tube as defined in claim 4 wherein said interior surface comprises the interior wall of an impervious metal pipe and said relatively porous compacted metal surface comprises at least one upstanding fin disposed on said impervious metal pipe.
6. A heat exchange tube as defined in claim 4 wherein said tubular body comprises an inner relatively impervious metal pipe and said relatively porous compacted metal surface comprises an elongated external jacket extending axially of said pipe and secured thereto.
7. A heat exchange tube as defined in claim 4 wherein

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said relatively porous surface is integral with said relatively impervious inner surface.

8. A centrifugal refrigeration system having a centrifugal compressor, a cooler containing refrigerant liquid, a condenser and an expansion device connected to form a refrigeration circuit, said cooler comprising a shell having a plurality of metal heat exchange tubes therein, means to pass a fluid to be cooled through the interior of said heat exchange tubes, said heat exchange tubes having a relatively impervious interior surface to substantially prevent leakage of said fluid through the walls of said tubes, the exterior surface of said heat exchange tubes comprising a relatively porous metal material, and means to directly contact refrigerant liquid with the porous exterior surfaces of said heat exchange tubes in said cooler to remove heat from said fluid to be cooled by vaporization of said refrigerant from said porous exterior surface.

9. A heat exchange apparatus comprising a shell, a plurality of connected heat exchange tubes within said shell, and a spray system for discharging a refrigerant liquid over said heat exchange tubes, said tubes comprising a plurality of interiorly relatively impervious hollow heat exchange pipes having a porous exterior heat transfer surface thereon, said heat transfer surface comprising a preformed porous metal body having a large number of surface interstices, said heat transfer surface comprising a plurality of preformed porous metal fins upstanding from said heat exchange pipes, said fins comprising compacted metal powder and having a large number of surface interstices.

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