July 27, 1965 D. G. RICH 3,196,634

REFRIGERATION SYSTEM

Filed March 29, 1963

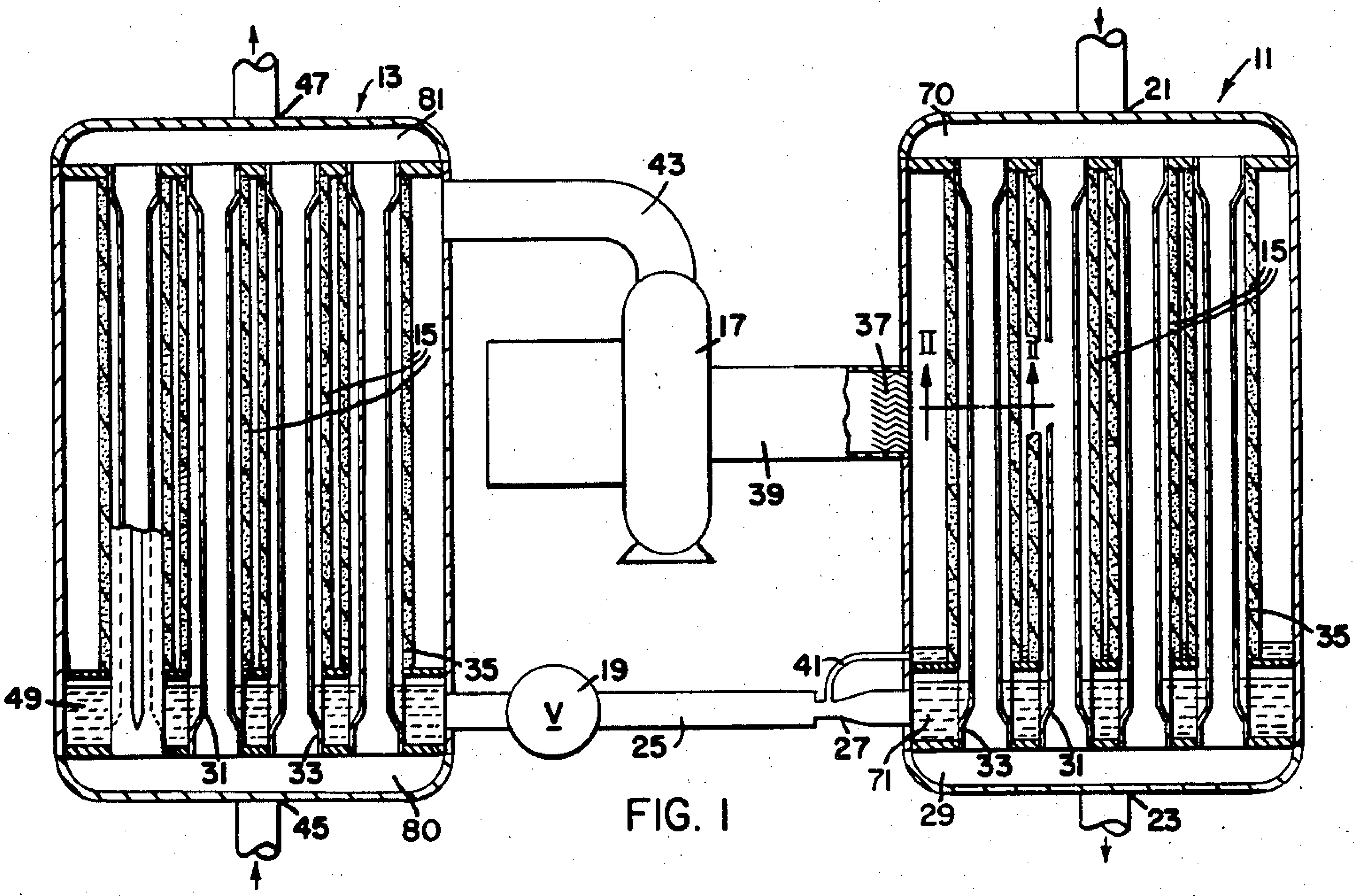

FIG. 1

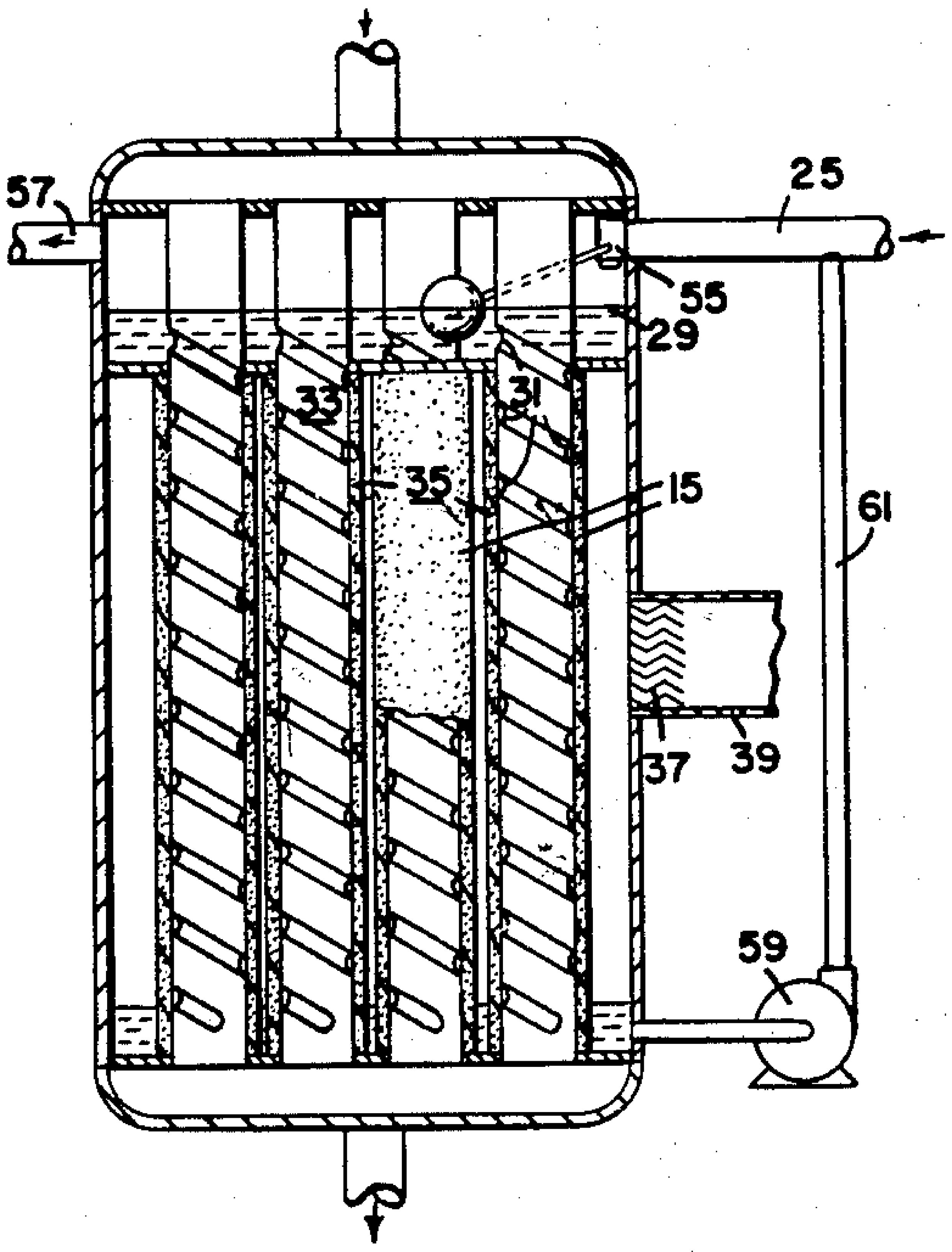

FIG. 3

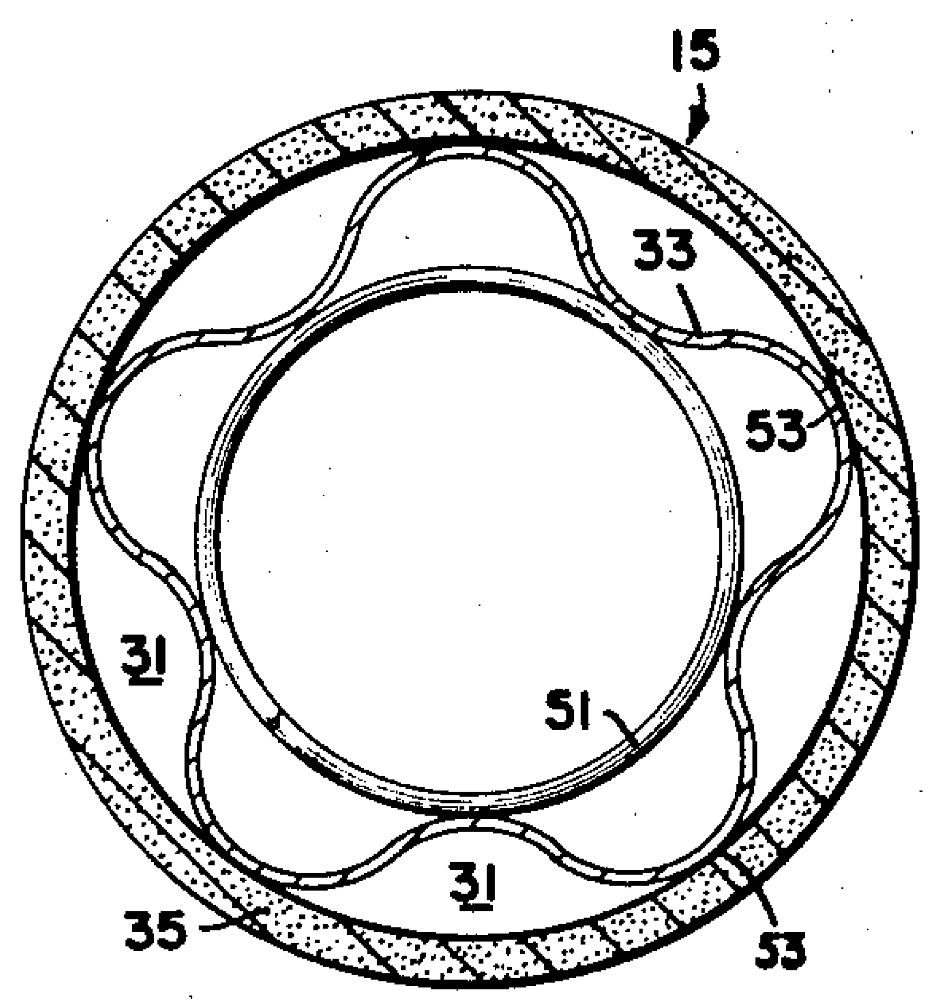

FIG. 2

INVENTOR.

DONALD G. RICH.

BY [signature]

ATTORNEY.

United States Patent Office 3,196,634
Patented July 27, 1965

3,196,634
REFRIGERATION SYSTEM

Donald G. Rich, Fayetteville, N.Y., assignor to Carrier Corporation, Syracuse, N.Y., a corporation of Delaware

Filed Mar. 29, 1963, Ser. No. 268,902
5 Claims. (Cl. 62—394)

This invention relates generally to refrigeration apparatus and more particularly to improved heat exchangers and heat exchange tubes of the type employed in refrigeration systems.

Refrigeration systems in general include four essential components, an evaporator, a condenser, a compressor, and an expansion device forming a closed circuit through which a volatile fluid medium passes to transfer heat from one point to another. This heat is absorbed from one fluid medium at a low temperature and dissipated to another fluid medium at a higher temperature.

Heat exchangers of the type herein described are adapted for use as components in a refrigeration system though other applications of this invention will become readily apparent to those skilled in the heat exchanger art. The basic operation of a heat exchanger involves the passage of two heat exchange mediums in relationship with each other such that heat is transferred from one of the heat exchange mediums to the other. An impervious metal tube having good thermal conducting characteristics is the most common form of heat exchanger. The tube wall provides a contact surface where vaporization of a liquid or condensation of a gas takes place as heat is exchanged between the internal and external fluid mediums. Naturally the heat transfer capacity of this type heat exchanger is dependent to a very large extent upon the contact surface available and limited by the temperature difference between the two fluid mediums. Another obvious limitation arises from the volumes of the two fluid mediums being passed in heat transfer relation. To increase the capacity of a given size heat exchanger, one of the well-known techniques is to employ fins on the outside surface of the tubes thereby providing a greater contact surface available to the external heat exchange medium.

Typical construction of heat exchangers employed in refrigeration systems and the like comprises a plurality of heat exchange tubes, frequently having an extended finned surface, disposed within an outer shell and connected to form a circuit for the passage through their interior of a heat exchange medium. The second heat exchange medium is connected for passage through the shell and passes across the exterior surface of the tubes.

One type heat exchanger depends upon vaporization of a liquid refrigerant on the extended tube surface. Since a substantial quantity of heat must be added to any liquid to vaporize it, heat may be removed from water passing through the interior of the tubes by conduction and convection. This type of heat exchanger is referred to herein as an evaporator.

Another type heat exchanger depends upon condensation of a relatively hot vaporous refrigerant on the extended tube surface which requires a substantial quantity of heat to be removed in order to condense the vaporous refrigerant. This heat may be dissipated to the water passing through the interior of the tubes by conduction and convection. This type of heat exchanger is referred to herein as a condenser.

In order to secure the maximum heat transfer capacity of an evaporator, spray systems or other means for discharging a quantity of liquid refrigerant over the entire extended tube surface are often employed to maintain a thin film of liquid on the exterior surface available for evaporation therefrom. Because of the low wettability

of the impervious metal heat exchange surface, substantial quantities of liquid must be discharged over the surface, otherwise dry areas will be present where only convective heat transfer may take place thereby losing the advantage of evaporative transfer. The surface tension of liquid may tend to make the liquid coalesce into droplets which produces further disadvantages in that the droplets become relatively thick and tend to insulate the tube to inhibit heat transfer. Increasing the quantity of discharged liquid presents the problem of building up a thick layer on the heat exchange surface further insulating the tube. Thus it is apparent that the most efficient heat transfer may be obtained by maintaining a uniform thin film of liquid over the heat exchange surface.

The performance of a condenser is likewise dependent upon the conditions occurring on the heat exchange surface. As in the evaporator, a thick layer of liquid on the heat exchange surface tends to insulate the tube and inhibit the heat transfer. It is thus important to remove the liquid condensing on the heat exchange surface while maintaining a uniform thin film thereon for conduction of heat from the hot vaporous refrigerant through the tube wall to be dissipated to the water flowing inside the tube. In this manner, the maximum heat transfer capacity may be realized.

It is an object of the present invention to provide heat exchangers with improved heat transfer capacities.

It is a further object of this invention to increase the contact surface of heat exchange tubes.

It is also the object of this invention to provide an improved evaporator for use in refrigeration systems.

It is likewise the object of this invention to provide an improved condenser for use in refrigeration systems.

It is still a further object of this invention to provide an improved method of making heat exchangers.

The accomplishment of these and other objects are achieved in the illustrated embodiments by providing a refrigeration system having metal heat exchange tubes of good thermal conducting characteristics, each tube comprised of one portion relatively impervious and the other portion relatively porous to provide a tube wall having an impervious surface on one side and a porous surface on the opposite side. These tubes are each constructed with a plurality of channels intermediate the impervious and porous surfaces to provide flow paths for liquid. If liquid is removed from the porous surface, as by evaporation, additional liquid is caused to flow in the channels to the porous surface thereby replenishing and maintaining a surface film of liquid. Conversely, if liquid is formed in the porous surface, as by condensing, the condensed liquid is caused to flow through the channels and carried away therefrom allowing additional liquid to form.

In the preferred embodiment a series of continuous indentations or flutes are formed in an impervious metal tube by rolling or any other suitable means substantially throughout the length of the tube. These indentations extend along the longitudinal axis of the tube and may be either parallel thereto or spirally arranged in helical fashion thereabout. The latter arrangement would provide higher heat transfer rates by providing a swirling action to the internal fluid medium which promotes mixing therein. Surrounding the impervious tube and mechanically bonded thereto is a porous tubular body formed of a compacted metal powder having good thermal conducting characteristics which with the indentations of the impervious tube form channels. It is also contemplated that the heat exchange tube may be formed of portions providing a tube wall having a porous internal surface and an impervious external surface for other heat exchange applications, for example, a direct expansion evaporator or an evaporative condenser.

As used in this application the term "porous" refers to the characteristic of a body having a large number of internal pores or voids. On at least one of the exposed surfaces and preferably all of the exposed surfaces of the body, the pores form surface interstices. 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 such that the fluid medium in contact with the porous surface is absorbed into the interior of the porous body. By the practice of this invention full advantage of heat transfer between fluid mediums passing in heat exchange relation may be realized because a very large heat transfer surface area in relation to its volume is provided.

The objects of this invention, as well as further objects and advantages, will become apparent from the description and drawings hereunder selected to illustrate a preferred embodiment of the present invention wherein:

FIGURE 1 is a diagrammatic view of a refrigeration system embodying applications of my heat exchange tube;

FIGURE 2 is a cross sectional view, on an enlarged scale, of the heat exchange tube, along line II—II of FIGURE 1, illustrating the addition of a helical wire for promoting turbulence; and

FIGURE 3 is a sectional view of the evaporative heat exchanger in FIGURE 1, as modified for top liquid feed distribution.

Referring particularly to FIGURE 1, there is shown a vertical evaporator 11 and a vertical condenser 13 embodying heat exchange tubes 15 of the present invention. The evaporator 11 and condenser 13 are combined with a compressor 17 and an expansion device 19 suitably connected to form a refrigeration system which may provide chilled water or other cooled medium for use in a circuit including room air cooling units of the type used in air conditioning systems for large multi-room buildings. A volatile fluid refrigerant is caused to flow in a closed circuit of this refrigeration system to transfer heat from the evaporator 11 to the condenser 13. In operation, heat is extracted from water or other fluid in contact with the exterior surfaces of the heat transfer tubes in evaporator 11 changing the refrigerant to its gaseous state, the compressor 17 comprises this gas to increase its saturation temperature, and then the gas is discharged into the condenser 13. The hot compressed gas is liquefied by dissipation of its heat to a suitable cooling medium such as water in contact with the exterior surfaces of the heat transfer tubes in condenser 13 and the liquid is then partially expanded through the expansion device 19 into the low pressure evaporator 11. Thus heat is absorbed from one fluid medium at a lower temperature and dissipated to another fluid medium at a higher temperature.

The vertical evaporator 11 of my preferred embodiment is of the well-known shell and tube type. Water or other fluid to be cooled enters a first fluid header 70 located at the top of the evaporator at connection 21, then passes interiorly through the heat exchange tubes 15 and leaves the bottom of the evaporator through a second fluid header 29 located at connection 23. The refrigerant liquid passes from the condenser 13 to a third fluid header 71 of the evaporator 11 through line 25; it leaves the condenser and is partially expanded to a lower pressure through an expansion device 19. However, before the refrigerant liquid enters third fluid header 71 of evaporator 11, it is expanded further through a venturi 27 for the purpose set forth below. Some of the liquid refrigerant flashes into a vapor during its expansion to the lower pressure of the evaporator, therefore a vapor, liquid mixture discharges from the venturi 27 into second fluid header 29 located in the lower portion of evaporator 11. This refrigerant mixture percolates up through a plurality of channels 31 in each of the tubes 15 of the evaporator, as best seen in FIGURE 2. In accordance with the construction of the heat exchange tubes 15 as hereinbelow set forth an impervious tube 33 is provided with a plurality of continuous indentations and surrounded by a porous metal body 35 to form said channels 31 between the impervious interior and porous exterior surfaces (FIGURES 1 and 2). The porous body 35 has a very large surface area in relation to its volume available for heat transfer and also the ability to absorb the liquid refrigerant from channels 31 thereby maintaining the heat exchange tubes 15 with a thin film of liquid for evaporation therefrom. The liquid flow into porous body 35 is primarily promoted by the pumping action of compressor 17 and may be assisted by a capillary action in most cases. The liquid is caused to vaporize because the porous body 35 is at a relatively high temperature between that of the warm water in the tubes and the cool saturated refrigerant. Thus a substantial quantity of heat is removed from the water, chilling it, and transferred to the refrigerant by the evaporation process. Refrigerant vapor leaves the porous exterior surface of body 35 and may pass through eliminators 37, if needed to remove any entrained liquid, as it flows out the evaporator 11 to the compressor 17 through a suction line 39. Even though eliminators may not always be needed, some liquid may pass through the porous body and collect at the bottom of the evaporator, in the vapor space above the distribution header 29, since it is not practical to control the amount of the refrigerant in each channel 31. Therefor to return any liquid collecting at the bottom of the evaporator, a return line 41 is provided to conduct this liquid to the venturi 27 where it is aspirated into the second header 29.

The compressor 17 compresses the refrigerant vapor and discharges it into the vertical condenser 13 through line 43. The condenser 13 is also of the well-known shell and tube type having a cooling medium, such as water, entering a first fluid header 80 the bottom of the condenser at connection 45, then passing interiorly through the heat exchange tubes 15 and leaving a second fluid header 81 located at the top of the condenser at connection 47. A third liquid header 49 is provided near the bottom of the condenser 13 to separate the high pressure vapor from the relatively lower pressure liquid collecting in this header and permits a pressure differential to build up as described more fully hereinafter. The refrigerant vapor entering the condenser 13, is condensed by the heat transfer action between the cooling medium in heat exchange tubes 15 which are likewise constructed as shown by FIGURE 2 and the warm vapor. The porous body 35 is at a relatively cool temperature near that of the impervious tube 33 and the high temperature refrigerant vapor is caused to condense within the porous body 35. The condensed liquid thus formed flows in the channels 31 and drains into the third fluid header 49 at the bottom of the condenser. Some sub-cooling is obtained in this manner due to the heat transfer between the liquid flowing in channels 31 and the impervious tube 33. The refrigerant flow in the condenser 13 is such that the vapor is actually drawn into the porous body 35 and the condensed liquid is extracted therefrom into the channels 31 because of a pressure drop which arises from a frictional effect as the refrigerant flows through the porous body 35 and channels 31. The third header 49 is employed to preserve the resulting lower pressure and maintain a pressure difference between the vapor space in condenser 13 and the space in header 49. This insures a flow of condensed liquid within channels 31 for best heat transfer performance which otherwise might not be possible. The liqud leaves condenser 13 from header 49 through line 25 wherein it is expanded before entering the evaporator 11 thus completing the refrigerant cycle.

The construction of the heat exchange tubes 15 is best shown by FIGURE 2. An impervious metal tube 33 having good thermal conducting characteristics, for example copper, is selected to comprise the base of each heat exchange tube. In this impervious tube, a plurality of continuous indentations are made by rolling or any other suitable method to be substantially throughout the length of the tube and parallel to one another. In one form the indentations run parallel to longitudinal axis of the tube as seen in FIGURE 1, however, they may run in a helical fashion as seen in FIGURE 3. The latter construction would promote internal turbulence to the water inside the tube and increase the water side heat transfer rate. Another method of promoting turbulence inside the tube is to provide a helical wire 51 inserted therein engaging the tube.

A porous heat transfer surface may be suitably formed of powdered metal having good thermal conducting characteristics, for example copper, by compacting and rolling the powdered metal into a tubular body, as indicated by numeral 35, with an inner diameter slightly larger than the outer diameter of the imprevious tube 33. In order to provide rigidity to this compacted body, it is desirable that the body be sintered, however, the operation must be such that the internal voids in the body are not sealed off from communication with each other, with the surfaces, or entirely eliminated by this operation. The impervious tube 33 is inserted within the porous body 35 and mechanically bonded thereto at the contiguous regions such as 53. Any suitable method of bonding may be used, for example brazing, wherein the impervious tube 33 is properly tinned at the regions 53 prior to its insertion within the porous body 35. The assembly of the impervious tube 33 and porous body 35 thereon may be placed in a brazing oven (not shown) to melt the solder and when cooled, will provide a good, low resistance thermal bond between the impervious tube 33 and the porous body 35. It is also possible to construct the heat exchange tubes 15 in accordance with the above method wherein the powdered metal comprises the base having the configuration as indicated by numeral 33 (FIGURE 2) and assembled inside an impervious tube.

Whether the porous body of the heat exchange tubes 15 becomes the external or internal member thereof is dependent upon the desired flow of the volatile refrigerant heat exchange medium in the type of application involved. The principal advantage of my construction is related to the high refrigerant side heat transfer performance which arises from the very large internal transfer area in relation to the volume provided by the porous body. Results have shown that overall heat transfer rates per foot of tube length are substantially higher with heat exchange tubes of my embodiment over conventional tubes having external fins thereon.

In FIGURE 3 there is shown a modification of the vertical evaporator 11 as adapted to distribute the refrigerant liquid from the top of the evaporator. The liquid from the condenser 13 (FIGURE 1) flows in line 25 where it is partially expanded by the expansion device 19 (FIGURE 1) and through a liquid level control device 55 prior to entering the distribution header 29. Since some of the liquid entering the header 29 flashes due to the lower pressures therein, a vapor return line 57 is provided leading to the suction connection 39 (FIGURE 1) which returns the vapor to the compressor 17 (FIGURE 1). The liquid in header 29 flows down the channels 31 and is evaporated from the porous surface of body 35 in the manner hereinbefore described. Any excess liquid collecting in the bottom of the evaporator may be returned to header 29 by a pumping means 59 and a return line 61 connected to liquid line 25 ahead of control device 55.

In addition to the high heat transfer performance to be gained from heat exchange tubes constructed in accordance with this invention, other advantages are afforded over prior art heat exchangers. For example, less refrigerant charge would be required due to the more intimate contact between the heat exchange mediums. Dry regions which unduly limit the capacity of prior art heat exchangers are eliminated by my construction. It is also possible to reduce the size heat exchangers and have them more compact. Furthermore, in evaporative type heat exchangers, spray systems, as frequently employed to maintain a thin film of liquid over the tubes may be eliminated. This not only reduces the initial cost of the system but tends to make it more reliable and less expensive to maintain.

Various other advantages and applications will occur to those skilled in the art and it is understood that this invention is not limited to the described embodiments but may be otherwise practiced within the scope to the following claims:

I claim:

1. In a refrigeration system, a heat exchanger for promoting heat transfer between refrigerant in said refrigeration system and another fluid medium, said heat exchanger comprising:

(1) a shell adapted to contain refrigerant vapor;

(2) a plurality of heat exchange tubes disposed within said shell, each of said heat exchange tubes comprising:

(a) a relative impervious, hollow, tubular, heat conducting, metal interior member,

(b) a relatively porous tubular, heat conducting metal, exterior member,

(c) one of said members being formed with a plurality of spaced, continuous indentations extending along the axis of said heat exchange tube, and forming with the other of said members a plurality of axially extending, spaced, continuous refrigerant channels having a porous wall portion, and

(d) said interior and exterior members being secured to each other, in heat exchange relation with each other, in the regions between said spaced refrigerant channels by an axially extending relatively low resistance thermal and mechanical bond;

(3) a first fluid header in communication with the hollow interior of said relatively impervious interior members of said heat exchange tubes adjacent one end thereof, and a second fluid header in communication with the hollow interior of said relatively impervious interior members of said heat exchange tubes, adjacent the other end thereof, for passing said other heat exchange medium through said plurality of heat exchange tubes;

(4) a third fluid header disposed in communication with said channels formed in said heat exchange tubes for passage of liquid refrigerant in said refrigeration system.

2. In a refrigeration system, a condenser for condensing refrigerant vapor, said condenser comprising:

(1) a shell adapted to contain refrigerant vapor;

(2) a plurality of heat exchange tubes disposed within said shell, each of said heat exchange tubes comprising:

(a) a relatively impervious, hollow, tubular, heat conducting, metal interior member,

(b) a relatively porous tubular, heat conducting, metal, exterior member,

(c) one of said members being formed with a plurality of spaced, continuous indentations extending along the axis of said heat exchange tube, and forming with the other of said members a plurality of axially extending, spaced, continuous refrigerant channels having a porous wall portion, and

(d) said interior and exterior members being secured to each other, in heat exchange relation with each other, in the regions between said spaced refrigerant channels by an axially extending relatively low resistance thermal and mechanical bond;

(3) means for passing refrigerant vapor into said shell and in contact with said porous exterior member;

(4) means for passing a cooling medium through said hollow interior member to cool said porous exterior member and to condense refrigerant vapor passing through said porous exterior member; and

(5) header means disposed in communication with said plurality of condensate channels formed in each of said heat exchange tubes for collecting condensate from said channels, said header including passage means for withdrawing condensate and passing it to a desired location.

3. A heat exchange tube comprising:

(1) a relatively impervious, hollow, tubular, heat conducting, metal interior member;

(2) a relatively porous tubular, heat conducting, metal, exterior member;

(3) one of said members having formed therein a continuous indentation extending along the axis of said heat exchange tube, and forming with the other of said members an axially extending, continuous channel having a porous metal wall portion; and

(4) said interior and exterior members being secured to each other, in heat exchange relation with each other, by an axially extending relatively low resistance thermal and mechanical bond providing relatively good heat transfer between said metal heat conducting members.

4. In a refrigeration system, a heat exchanger for promoting heat transfer between refrigerant in said refrigeration system and another fluid medium, said heat exchanger comprising:

(1) a shell adapted to contain refrigerant vapor;

(2) a plurality of heat exchange tubes disposed within said shell, each of said heat exchange tubes comprising:

(a) a relatively impervious, hollow, tubular, heat conducting, metal interior member,

(b) a relatively porous tubular, heat conducting, metal, exterior member,

(c) one of said members being formed with a plurality of spaced, continuous indentations extending along the axis of said heat exchange tube, and forming with the other of said members a plurality of axially extending, spaced, continuous refrigerant channels having a porous wall portion, and

(d) said interior and exterior members being secured to each other, in heat exchange relation with each other, in the regions between said spaced refrigerant channels by a relatively low resistance thermal and mechanical bond;

(3) a first fluid header in communication with the hollow interior of said relatively impervious interior members of said heat exchange tubes adjacent one end thereof, and a second fluid header in communication with he hollow interior of said relatively impervious interior members of said heat exchange tubes, adjacent the other end thereof, for passing said other heat exchange medium through said plurality of heat exchange tubes;

(4) a third fluid header disposed in communication with said channels formed in said heat exchange tubes for passage of liquid refrigerant in said refrigeration system; and

(5) said heat exchanger comprising an evaporator, and said refrigeration system incuding the combination therewith of refrigerant restriction means to pass a mixture of refrigerant liquid and refrigerant vapor into said channels to promote passage of liquid refrigerant through said channels and evaporation of liquid refrigerant from said porous exterior metal member, said refrigeration restriction means comprising a venturi pipe section adjacent said third fluid header, said system further including a passage connecting said venturi section into said shell to discharge said mixture of refrigerant liquid and refrigerant vapor into said channels and induce a return of any liquid refrigerant accumulated in said shell to said channels in the heat exchange tubes.

5. In a refrigeration system, an evaporator for promoting heat transfer between refrigerant in said refrigeration system and another fluid medium to be cooled, said evaporator comprising:

(1) a shell adapted to contain refrigerant vapor;

(2) a plurality of heat exchange tubes disposed within said shell, each of said heat exchange tubes comprising:

(a) a relatively impervious, hollow, tubular, heat conducting, metal interior member,

(b) a relatively porous tubular, heat conducting, metal, exterior member,

(c) one of said members being formed with a plurality of spaced, continuous indentations extending along the axis of said heat exchange tube, and forming with the other of said members a plurality of axially extending, spaced, continuous refrigerant channels having a porous wall portion, and

(d) said interior and exterior members being secured to each other, in heat exchange relation with each other, in the regions between said spaced refrigerant channels by an axially extending, relatively low resistance thermal and mechanical bond;

(3) a first fluid header in communication with the hollow interior of said relatively impervious interior members of said heat exchange tubes adjacent one end thereof, and a second fluid header in communication with the hollow interior of said relatively impervious interior members of said heat exchange tubes, adjacent the other end thereof, for passing said other heat exchange medium through said plurality of heat exchange tubes;

(4) a third fluid header disposed in communication with said channels formed in said heat exchange tubes for passage of liquid refrigerant in said refrigeration system; and

(5) means to withdraw any refrigerant liquid accumulated about said tube in said shell and to pass said withdrawn liquid refrigerant into said channels.

References Cited by the Examiner

UNITED STATES PATENTS

1,570,995	1/26	Lony	62—115
1,836,318	12/31	Gay	62—471 X
2,168,438	8/39	Carrier	62—115
2,183,509	12/39	Smith	62—394
2,282,627	5/42	Weiss	62—394
2,448,315	8/48	Kunzog	165—180 X
2,456,775	12/48	Fausek et al.	165—141
2,519,844	8/50	Mojonnier	62—512
2,723,880	11/55	Axelson	165—141 X
2,766,597	10/56	Gieck	62—315 X
2,914,091	11/59	Barnes et al.	165—180 X
2,941,759	6/60	Rice et al.	62—316 X
2,966,340	12/60	Chapman	165—180 X

ROBERT A. O'LEARY, *Primary Examiner.*