Nov. 18, 1947. R. H. BURGESS 2,431,228

HEAT EXCHANGE UNIT

Filed June 4, 1945

Fig. 1.

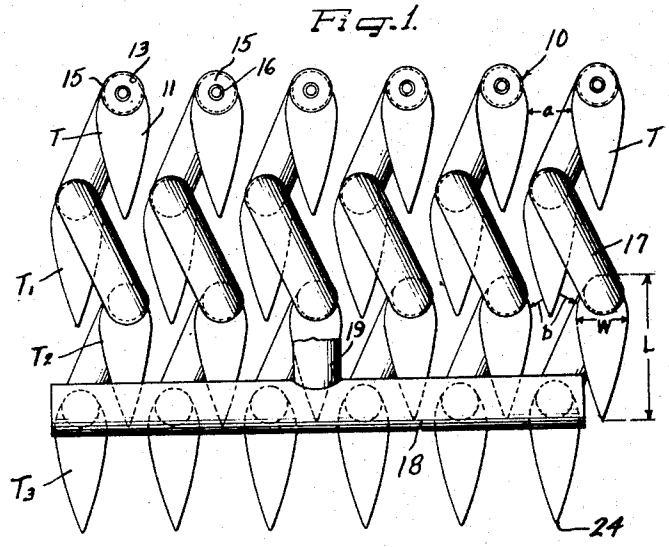


Fig. 4.

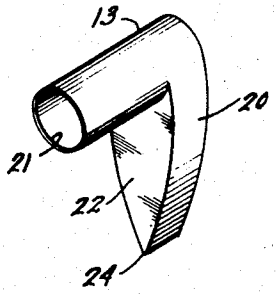


Fig. 2.

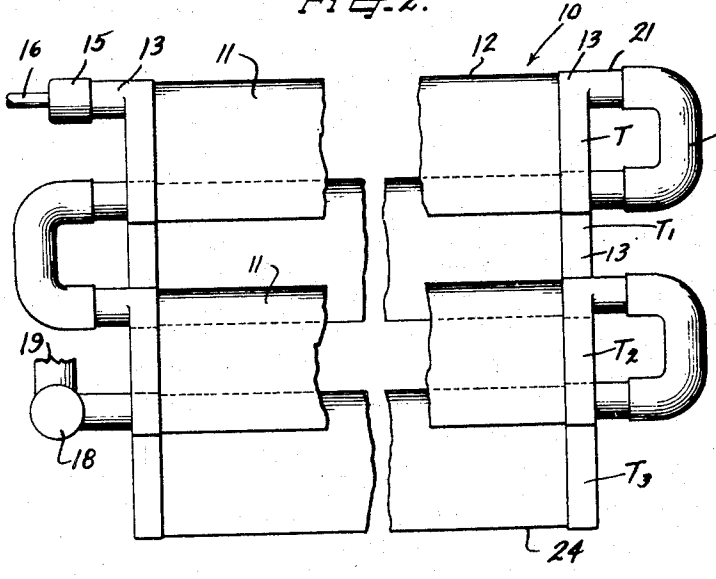


Fig. 5.

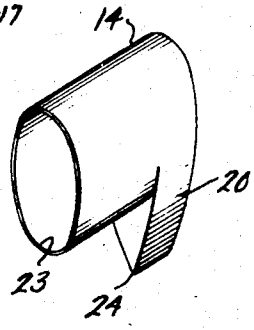
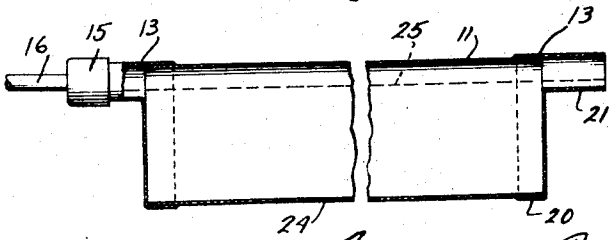


Fig. 3.



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HEAT EXCHANGE UNIT

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4 Claims. (Cl. 62—126)

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This invention relates to a heat exchange unit, the principles of which are applicable to a refrigerator evaporator unit, a refrigerator condenser unit, or a cooling unit in air conditioning systems and the like. More particularly, the invention relates to an evaporator unit for use in a refrigerating system employing a normally gaseous refrigerant.

In the conventional type of evaporator as used by the commercial refrigeration and/or air conditioning industry today, tubes of circular cross section are generally used for the flow of the refrigerant therethrough. In the gravity flow, direct expansion type of evaporator unit, the refrigerant in liquid state is introduced into the uppermost tube or tubes, for evaporation therein and for gravity flow of the refrigerant, while partly in liquid and partly in gaseous state, to lower rows of tubes. The heat transfer is effected through the walls of the tubes between the external flow of air or other gas about the tubes and the refrigerant within the tubes.

The factors that should be considered in evaporator design are the following:

1. Outside air film at prime surface.
2. Thermal conductivity of tube or prime surface.
3. Inside refrigerant film on prime surface.
4. Resistance to air flow.
5. Velocity of air through or over evaporator tubes or units.
6. Fan load, in the case of forced convection jobs.
7. Area of prime surface.
8. Refrigerant-holding capacity of evaporator.
9. Free gas area inside evaporator.
10. Velocity of liquid through evaporator.
11. Velocity of gas through evaporator.
12. Oil flow restriction.
13. Gas flow restriction.
14. Liquid flow restriction.

If each of the foregoing factors be analyzed, it will be found that conventional evaportor designs violate some of the physical laws governing aerodynamic and thermodynamic principles as applied to a conventional gravity or forced convection commercial evaporator. One such violation is the use of round tubes without efficient liquid flow restriction, as the prime conductor in the evaporator unit, whether such tubes be connected in series or in parallel and regardless of how the refrigerant is fed to the evaporator.

From an aerodynamic viewpoint, the round or circular tube is inefficient as compared with a

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streamlined tube, such as a tube of tear-drop shape in cross-section, since the round tube has about fifteen times the resistance to air flow that the streamlined tube has. By using a streamlined tube in the case of forced convection units, the load on the fan is greatly decreased. Furthermore, whether of the forced convection or natural convection type, the thermal transmission efficiency of heat from the air to the refrigerant in the case of streamlined tubes is greatly increased by reason of decreasing the air film resistance thermally on the exterior surfaces of the tubes. This latter is accomplished by eliminating "dead air" films surrounding the tube surface.

In any evaporator unit the liquid refrigerant must be converted from a liquid into a gas in passing through the unit, if of the direct expansion type. In the case of dichlorodiflouromethane, a pound of this refrigerant (under standard-ton conditions) in liquid state has a volume of 0.0111 cubic feet, whereas the same pound in gaseous state, at the same temperature and pressure in equilibrium with some of the compound in liquid state, has a volume of 1.485 cubic feet. In a direct expansion evaporator it is possible to occupy approximately 50% of the internal volume of the evaporator with liquid refrigerant during operation thereof. If the liquid were uniformly distributed throughout the evaporator, the velocity of the gas would be more than 130 times that of the liquid for the liquid for the same rate of flow by weight. Due, however, to the cohesive attraction of like molecules of any matter, there is a tendency for the gas to carry the liquid through the evaporator tubes at the same velocity as that at which the gas should travel. If this should happen there would be no evaporation of the liquid and therefore no refrigeration, unless the refrigerant entered the evaporator at a lower temperature than the temperature of the substance to be cooled.

If an evaporator is to accomplish the desired results, it is necessary, then, that the gas and liquid travel through the evaporator tubes at different velocities. The greater the difference between the two, the higher will be the rate of evaporation and the rate of heat transmission. If there is a free gas area above the surface of the liquid, a higher gas velocity will be obtained and there will be little danger of slugs of liquid being carried along with the gas through the tubes.

According to the principles of my present invention, advantage is taken of known thermo-

dynamic and aerodynamic principles in order to obtain a higher thermal efficiency in the transfer of heat from the circumambient air or other gas and the refrigerant flowing through the evaporator tubes. Each of the tubes is streamlined to reduce its resistance to air flow. By the term "streamlined" is meant a surface so contoured as to offer the minimum amount of resistance to the flow of air over and past the surface. In general, a streamlined tube will be one having the shape of a tear-drop in cross-section. For instance, if W represents the greatest width of the section, then the greatest length of the section, L, should equal 3W. For most efficient spacing of the streamlined tubes, the minimum distance between laterally spaced tubes at the same elevation should be the same as the maximum width of the tube sections, and the minimum spacing between adjacent tubes in adjoining vertically spaced tiers should be about one-half such width, or

$$\frac{W}{2}$$

Further, in accordance with my present invention, the streamlined tubes are provided with end fittings having nipples or extensions which may be circular or elliptical in cross section. Such extensions joined integrally to the tube ends and are connected at points adjacent the wider edges of the tubes, preferably so as to form continuations of the wider edges of the tubes that are substantially flush with such edges. The end nipples or extensions of the tubes are thus spaced from the thinner edges of the tubes, which constitute the lower edges when the tubes are arranged in a refrigeration evaporator. By virtue of this arrangement, therefore, the liquid portion of the refrigerant is trapped in the lower portions of the tubes, while the gaseous portion of the refrigerant is free to pass at relatively high velocity from one tube to the next. Preferably, end fittings connect corresponding upper end portions of the tubes in vertically adjacent tiers so as to serve primarily for gas flow communication between the tubes while causing the liquid refrigerant to be trapped in the lower portions of the tubes. There is therefore little likelihood of slugs of liquid refrigerant becoming entrained in the gas flow through the tubes of the evaporator unit.

It is therefore an important object of this invention to provide a heat exchange unit, such as a refrigeration evaporator unit, in which the refrigerant tubes are streamlined and arranged in a plurality of horizontal tiers, with the tubes in vertically adjacent tiers staggered so as to present the minimum resistance to the flow of air downwardly over and past the tubes, whereby an efficient rate of heat transfer is obtained, both in natural convection and in forced convection installations.

It is a further important object of this invention to provide a refrigeration evaporator unit in which the refrigerant tubes are streamlined, with their wider edges constituting the leading edges, and to provide end fittings connecting the upper portions of the ends of such tubes, whereby liquid refrigerant is entrapped in the lower portions of the tubes and gaseous refrigerant is permitted to flow freely at a velocity independent of that of the liquid refrigerant from one tube to the next in the series.

It is a further important object of this invention to provide a refrigeration evaporator unit comprising a plurality of horizontal tiers of tubes, with the vertically adjacent tubes arranged in

staggered relationship and with the tubes each of a streamlined contour so as to offer the minimum resistance to air flow through the unit, the tubes in vertically adjacent sections being connected individually by end fittings joining the top portions only of the tubes, thereby causing the liquid portion of the refrigerant to be largely trapped in the bottom portions of the tubes and insuring more rapid evaporation and a higher velocity of the gaseous portion of the refrigerant through the unit.

Other and further important objects of my invention will become apparent from a consideration of the following detailed description, taken in conjunction with the accompanying drawings.

On the drawings:

Figure 1 is an end elevational view of a refrigeration evaporator unit embodying the principles of my invention.

Figure 2 is a broken side elevational view of the unit.

Figure 3 is a longitudinal sectional view of one of the tubes with its end fittings.

Figure 4 is a perspective view of an end fitting for brazing or otherwise securing to an end of a tube.

Figure 5 is a perspective view of a modified form of end fitting.

The reference numeral **10** indicates generally a refrigeration evaporator unit embodying the principles of my invention. While the invention will be described as applied to the construction of an evaporator unit, it will be understood that the principles of my invention are broadly applicable to all types of heat exchangers involving the flow of a fluid that is partly in liquid and partly in gaseous form through a closed path, such as defined by individually connected tubes, for effecting a heat transfer between the fluid passing through the tubes and the circumambient air or gases passing into contact with the external surfaces of the tubes.

The refrigeration evaporator unit **10** comprises a plurality of horizontal tiers T, T_1, T_2 and T_3 of tubes **11**. Said tubes **11** are arranged in laterally spaced relationship in the individual tiers, with the tubes of one tier staggered with relation to the vertically adjacent tubes in the next adjoining tiers. Each of the tubes **11** is streamlined so as to offer the minimum of resistance to the flow of air, or other gas, through the unit **10**.

In steamlining the tubes and in arranging the tubes in spaced relation in the unit **10**, certain mathematical formulae are closely adhered to for the purpose of reducing the air resistance of the unit to a minimum. For instance, if L designates the longer dimension of a section of a tube **11** and W the greater width of a section of the tube **11**, then the relationship existing can be expressed by the equation $L=Wx3$, or

$$W=\frac{L}{3}$$

With respect to the spacings between the adjacent tubes **11** and any of the horizontal tiers, the minimum spacings, represented by the letter a, should be equal to the width W of the individual tube. Further, if the minimum spacing between vertically adjacent tubes be represented by the letter b, then for most effective spacing

$$b=\frac{a}{2}$$

By employing these mathematical relationships in the construction of a refrigeration evaporator

unit, one may realize the most efficient rate of heat transfer between the unit and the air, or other gas, passing through the unit. The direction of the flow of air through the unit 10 will, of course, be downwardly, whether the unit is used in a natural convection system or in a forced convection system. Accordingly, the wider upper edges 12 of the tubes 11 will constitute the leading edges in terms of the flow of air through the unit.

Each of the tubes 11 consists of a straight, open-ended length of tubing of the steamlined character already referred to. The tubes may be formed of any of the materials commonly used in the construction of evaporator tubes, such as copper, brass, stainless steel and the like. Preferably, the tubes 11 are formed of copper because of its high coefficient of heat transfer. The walls of the tubes are made as thin as a proper factor of safety will permit.

Each of the tubes 11 is provided at its ends with an end fitting 13 or 14 (Figs 4 or 5) for connecting the tubes 11 to each other or into the refrigerant circulatory system of the refrigerator unit. As shown, the upper row T of tubes 11 is provided at the front ends of the tubes with end fittings 13 and these end fittings are provided with caps 15 into which extend inlet tubes 16 for conducting a liquid refrigerant into said upper tier of tubes. At their rear ends the tubes 11 in the upper tier T are connected through their end fittings 13 by means of their U-bends 17 to the end fittings 13 of the tubes 11 in the next tier T_1. Similarly, at their front ends, the tubes 11 in the tier T_1 are connected to the tubes 11 in the tier T_2 by means of U-bends 17, and the tubes of tier T_2 are likewise connected to the tubes in the tier T_3 at the rear of the unit. The front ends of the tubes in the lowermost tier T_3 are connected through a manifold 18 to a gas outlet and suction line 19.

With further reference to the end fittings 13, each of said end fittings comprises a streamlined socket portion 20 adapted to fit over an end of a tube 11, and a cylindrical portion 21 extending from the larger end of the socket portion 20 and preferably forming a flush continuation of the upper wider edge of said socket portion. The socket portion 20 is adapted to be inserted over an open end of a tube 11 and to be brazed or otherwise integrally secured to said tube. Hydrogen brazing, silver soldering, or other method may be used to effect a good thermal bond between the socket portion 20 and the end of a tube 11. Each end fitting 13 has an end wall 22 that closes an end of a tube 11 when the end fitting is secured in place.

A modified form of end fitting 14, illustrated in Figure 5, is provided with an extension 23 of elliptical cross-section, instead of circular cross-section. Said extension 23, like the extension 21, has the major portion of its upper wall surface flush with the wider edge portion of the socket 20. Thus the extensions 21 and 23 are both adjacent the upper, or wider, edges of the tubes 11 when the end fittings are in place on the tube ends, and said extensions are therefore spaced above the lower, thinner edges 24 of the tubes. The purpose of this will be apparent in the following description.

Liquid refrigerant enters the tubes 11 in the upper tier T through the small diameter tubing 16. The end of said tubing 16 may be joined by a manifold (not shown) or may be individually supplied with liquid refrigerant from the source

of liquid refrigerant in the particular refrigeration system. The liquid refrigerant entering the upper tier of tubes may be introduced at such a rate as to fill each of the tubes 11 in said upper tier T to a height such as that indicated by the dotted line (Fig. 3), which may be slightly above the bottom wall of the end fitting extension 21. In that case, there would be some flow of liquid refrigerant from the tubes in the upper tier T through the end fittings 13 and U-bends 17 into the tubes in the next lower tier T_1. The major proportion of the cross-sectional areas of said extensions 21 and U-bends 17, however, would be left open for the flow of gaseous refrigerant formed by the evaporation of the liquid refrigerant in the bottoms of the tubes 11.

There will, of course, be correspondingly less refrigerant in liquid phase in the lower tiers T_1, T_2 and T_3, and, in fact, if the flow of refrigerant is properly controlled, no liquid refrigerant will be permitted to pass out of the lower tier of tubes into the manifold 18, but will be trapped in the lower portions of the tubes in said lowermost tier T_3.

There is thus a free gas area above the level 25 of the liquid refrigerant in each of the tubes 11 in each of the tiers of the unit. By regulating the rate of flow of refrigerant entering the evaporator and by maintaining the pressure on the surface of the liquid refrigerant in the tubes lower than the saturated vapor pressure at that particular temperature, effective refrigeration can be produced. The lower vapor pressure referred to is maintained by effecting a proper velocity of the gas through the unit, and this is made possible by reason of the fact that the end fittings are connected to the upper portions only of the tubes 11, so that there are no slugs of liquid refrigerant in the gas flow passages to slow down the flow of gas therethrough.

It will thus be appreciated that I have provided an efficient construction and arrangement of tubes and end fittings for assembly into a refrigeration evaporator unit, whereby the unit may function with maximum efficiency of rate of heat transfer between the refrigerant and the circumambient air or other gas passing through the unit. At the same time, a minimum air flow resistance is offered because of the streamlining of the tubes and the proper spacing and arrangement of the tubes in the unit.

I claim as my invention:

1. An evaporator unit for a normally gaseous liquid refrigerant, comprising a plurality of tiers of tubes of generally tear-drop cross-section, said tubes being arranged when said unit is mounted for operation with their rounded edges as the leading edges uppermost with respect to the flow of air downwardly over and past said tubes and with the tubes in each tier laterally spaced at the same elevation and staggered with respect to tubes in vertically adjacent tiers, and end fittings individually connecting corresponding upper end portions of the tubes in vertically adjacent tiers, whereby said end fittings serve primarily for gas flow communication between said tubes while liquid refrigerant is trapped in the lower portions of said tubes.

2. A heat exchange unit for the exchange of heat between a flowing body of an external gas and an internal fluid that is present in said unit in both gaseous and liquid states under the conditions of operation thereof, said unit comprising a plurality of tiers of tubes of generally tear-drop cross-section, said tubes being arranged

when said unit is mounted for operation with their rounded edges as the leading edges with respect to the flow of said external gas over and past said tubes and with the tubes in each tier laterally spaced at substantially the same elevation and staggered with respect to tubes in vertically adjacent tiers, and end fittings individually connecting corresponding tube ends of tubes in vertically adjacent tiers at the level of the corresponding leading edges but not including the levels of the trailing edges of said tubes, whereby said end fittings serve primarily for flow communication between leading edge portions of said tubes of said internal fluid in one of said states while said fluid in the other of said states is trapped in the trailing edge portions of said tubes.

3. In a device of the character described, a heat exchange unit for causing a change of phase of a fluid medium and having an inlet and an outlet, said unit comprising horizontal tiers of lengths of tubing each of generally oval cross section, said tiers overlying one another and the tubing lengths of one tier being staggered with respect to the tubing lengths of the next tier vertically spaced therefrom, end fittings each connecting the upper portion only of one end of a tubing length in one row to the corresponding end of a tubing length in the next row vertically spaced from said first-mentioned row, said tubing lengths forming traps for liquid and the upper portion of said lengths and said fittings forming a passage for conducting primarily the vapor portion of said medium and extending from said said inlet to said outlet.

4. In a device of the character described, a heat exchange unit for causing a change of phase of a fluid medium and having an inlet and an outlet, said unit comprising horizontal tiers of lengths of tubing each of generally oval cross

section, said tiers overlying one another and the tubing lengths of one tier being staggered with respect to the tubing lengths of the next tier vertically spaced therefrom, end fittings each relatively constricted in cross sectional area as compared to a tubing length and each connecting the upper portion only of one end of a tubing length in one row to the corresponding end of a tubing length in the next row vertically spaced from said first-mentioned row, said tubing lengths forming traps for liquid and the upper portion of said lengths and said fittings forming a passage for conducting primarily the vapor portion of said medium and extending from said inlet to said outlet.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,874,009	Henshall et al.	Aug. 30, 1932
1,895,755	Freeman	Jan. 31, 1933
2,257,558	Whittle	Sept. 30, 1941
1,975,925	Compo	Oct. 9, 1934
443,220	Detrick	Dec. 23, 1890
1,957,292	Reeves	May 1, 1934
2,232,568	Spofford	Feb. 18, 1941
1,797,535	Trane	Mar. 24, 1931
2,109,270	Krackowizer	Feb. 22, 1938

FOREIGN PATENTS

Number	Country	Date
466,371	France	May 11, 1914
178,245	Germany	Nov. 15, 1906
309,798	Great Britain	Apr. 18, 1929