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[54] **ADVANTAGEOUS CONFIGURATION OF TUBING FOR INTERNAL BOILING**

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[22] Filed: **Nov. 4, 1970**

[21] Appl. No.: **86,708**

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[63] Continuation of Ser. No. 674,611, Oct. 11, 1967, abandoned.

[52] **U.S. Cl.** **165/1,** 165/179, 62/115, 62/527

[51] **Int. Cl.** **F28f 1/08**

[58] **Field of Search** 165/177, 179, 184, 1; 62/527, 56

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[57] **ABSTRACT**

Tubing designed for internal boiling, particularly of substituted hydrocarbon refrigerants provided with an unobstructed interior having radially inwardly extending ribbing comprising a multiplicity of convolutions extending around the tubing, the axial pitch P of adjacent convolutions being not greater than 3/4 inch, the depth *d* of the ribbing being between 1/64 inch and 3/64 inch, the ratio P/*d* being between 5 and 25.

26 Claims, 5 Drawing Figures

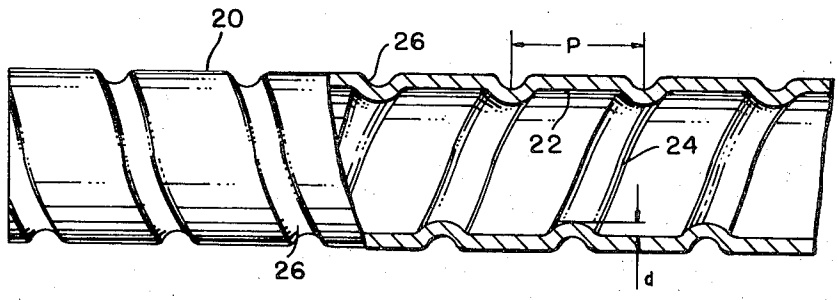


FIG. 1

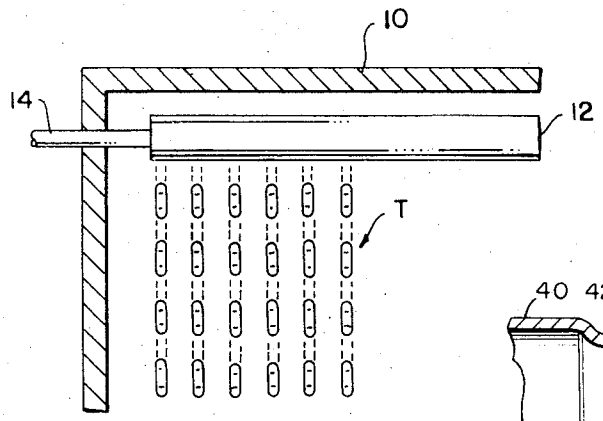
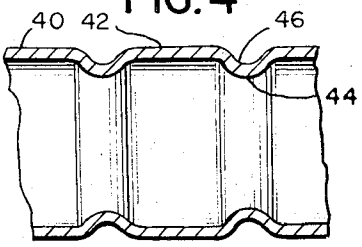


FIG. 4



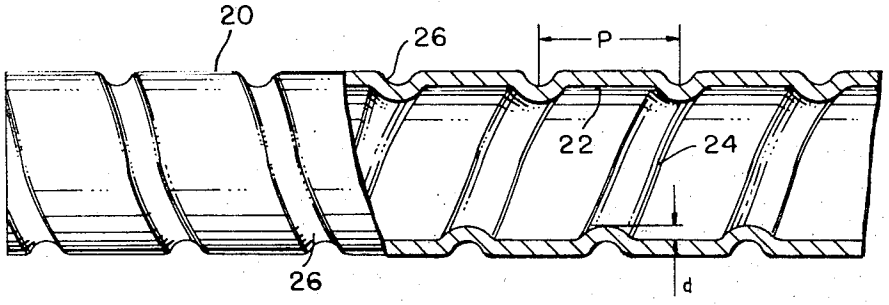


FIG. 2

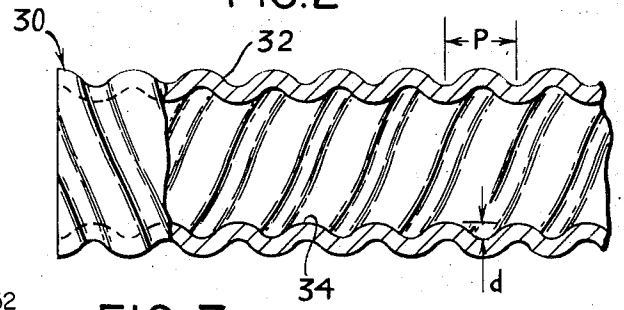
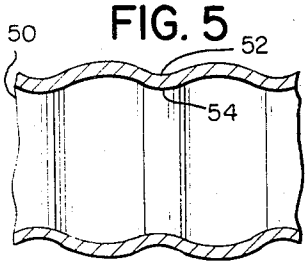


FIG. 3

FIG. 5



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ADVANTAGEOUS CONFIGURATION OF TUBING FOR INTERNAL BOILING

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation of our prior copending application Ser. No. 674,611, filed Oct. 11, 1967.

BACKGROUND OF THE INVENTION

The problem of obtaining optimum results in boiling of a liquid within a tube by heat transfer from ambient fluid to the material in the tube presents many difficulties. An excellent example where this problem arises is in refrigeration such for example as in water cooling or in space cooling where a substituted hydrocarbon refrigerant such for example as freon is introduced into the inlet end of the tubing in substantially liquid phase, is caused to boil by heat transfer as it passes through tubing, and exits the tubing in substantially vapor phase either with or without super-heat.

The problem of extracting the maximum amount of heat from the ambient fluid and transmitting it to the liquid at the interior of the tubing to cause boiling or vaporization of the same becomes essentially a problem of heat transfer from the inner surface of the tubing to the liquid therein. A the present time the standard commercial tubing proposed for solving this problem is the so-called star-insert tubing disclosed in Hinde U.S. Pat. No. 2,960,114. This tubing comprises an insert having a central stem and radial fins. The tubing is drawn or otherwise forced radially inwardly into tight contact with the radially outer ends of the fins. Tubing of this type of course offers very substantial resistance to flow with corresponding high pressure drop and is moreover necessarily of relatively large diameter and is expensive both from the standpoint of material and also production costs.

Some effort has been made to avoid the inherent objections to this star-insert tubing and this has for the most part involved the use of prime tubing which fails to provide an inner surface heat transfer function of acceptable efficiency.

BRIEF SUMMARY OF THE INVENTION

As a result of extensive testing it has been found that a relatively small modification of essentially prime thin-walled tubing converts it to a configuration having excellent heat transfer properties. Specifically, the solution to the problem is to provide tubing having its interior unobstructed except to the extent that its inner surface is modified to provide radially inwardly extending ribbing in which the ribbing comprises a multiplicity of convolutions extending around the tubing. The ribbing may be in the form of axially spaced circumferentially extending separate ribs. Conversely, it may be in the form of a single helical rib or a multiplicity of helical ribs. In either case the axial spacing or pitch P of adjacent convolutions, for refrigeration application, does not exceed ¾ inch. The depth *d* or radial extension of the ribbing above the smooth cylindrical interior surface of the tubing is desirably about 1/32 inch, and in any case, between 1/64 inch and 3/64 inch, the ratio of pitch to depth of convolution P/*d* being between 5 and 25.

The tubing is thin-walled metal tubing having a wall thickness of not more than 0.075 inch.

It is accordingly an object of the present invention to provide an evaporator construction, preferably for use in refrigeration in which tubing is provided into which a substituted hydrocarbon refrigerant is introduced in substantially liquid phase and which is boiled or evaporated by transfer of heat from ambient fluid during transit and which leaves the tubing in substantially vapor phase, the tubing providing exceptionally good transfer of heat from ambient fluid to the refrigerant by reason of the provision of ribbing on the interior surface of the tubing extending in a multiplicity of convolutions around the tubing.

It is a further object of the present invention to provide an evaporator construction as described in the preceding paragraph in which the axial pitch P of adjacent convolutions does not exceed ¾ inch, the depth *d* of the ribbing being between 1/64 inch and 3/64 inch, and the ratio of pitch to depth P/*d* being between 5 and 25.

It is a further object of the present invention to provide tubing of special configuration designed for use in effecting internal boiling.

Other objects and features of the invention will become apparent as the description proceeds, especially when taken in conjunction with the accompanying drawing, illustrating a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a fragmentary sectional view of an evaporator constructed in accordance with the present invention.

FIG. 2 is an enlarged elevational view of a portion of evaporator tubing, with parts broken away.

FIG. 3 is a view similar to FIG. 2 showing a different embodiment of the present invention.

FIGS. 4 and 5 are fragmentary sectional views showing further embodiments of the present invention.

DETAILED DESCRIPTION

Industrial applications are common in which a liquid flowing inside of a tube is caused to absorb heat from ambient fluid outside the tube wall and as a result will become heated and will boil or vaporize. For instance, in the so-called "direct-expansion" or "dry-expansion" water chiller, commonly used in air conditioning and refrigeration, a refrigerant such as a halocarbon or a hydrocarbon will be the boiling fluid. In this application the cold refrigerant fluid which may be partially vaporized due to expansion through the expansion valve, enters the heat transfer tubing in the evaporator. As heat is absorbed, the percentage of vapor in the flowing refrigerant stream will increase until at the exit end of the tubing virtually all of the liquid will have been converted to vapor, and in some cases the vapor may even be superheated to a few degrees with respect to the exit pressure.

The boiling of a liquid which is being heated while flowing through a tube is a rather complex phenomenon. For instance, several different types of flow or flow "flow-regimes"have been recognized. These regimes have been referred to in the literature as the nucleate-boiling regime, the annular-flow regime, and the mist-flow regime. Different mechanisms of heat transfer prevail in different regimes.

The mist-flow regime is also called the fog-flow regime. It is a liquid-deficient condition in that as the liquid has been progressively converted to vapor the amount of liquid left is insufficient to wet the walls of the tube, and the liquid that exists is largely in the form of droplets which are suspended in the flowing stream of vapor. Therefore, further heat transfer becomes difficult because of the low thermal conductivity of vapor as compared with liquid; that is, heat that is being conducted through the tube wall to the inside of the tube must find its way across a vapor barrier in order to cause the remaining liquid droplets to evaporate.

Recognition that a very high thermal reistance of some form was involved on the inside of the system has led to different commercial configurations being used and a common form provides longitudinal internal fins or inserts (so-called "star inserts") which divide the space within a sheath tube into various radial sectors. Tubing of the type just described which may be referred to as "LIF" tubing, will generally provide 50 to 100 percent more heat transfer (or boiling capacity) than corresponding plain tubes of the same outside diameter. Investigation in this field seems to establish that the improvement in effectiveness of LIF tubing is substantially due to providing additional effective inside surface area.

While LIF tubing provides greatly increased heat transfer as compared to plain or prime tubing of the same diameter, it is subject to the objection that the internal configuration provides greatly increased resistance to flow or increased pressure drop, and the further great objection of increased costs due both to a very large increase in material as well as substantially increased cost due to production costs.

The present invention relates to a different type of tubing having a configuration which has been found to be very effective for the promotion of heat transfer or boiling capacity, but which does not depend on a large increase of internal surface area. This type of configuration may be advantageously employed because the amount of metal may be reduced, and because the tubing is more economical to process to the final form.

The tubing configuration in accordance with the present invention, is provided with an unobstructed interior except for a relatively minor configuration of the interior surface. The interior surface of the tubing is generally a smooth cylindrical surface provided with ribbing comprising a multiplicity of convolutions extending around the tubing, as will presently be described.

Referring now to the drawing there is illustrated a portion of an evaporator having an enclosure **10** within which is provided tubing in the form of a multiplicity of coils of tubing T. The coils, as is familiar in the art, constitute a multiplicity of straight tube sections interconnected at their ends by U-shaped connectors. The coils generally are connected to a header **12** to which refrigerant is fed by a line **14** from a condenser through a suitable expansion valve. The evaporator includes an exit header (not shown) to which the coils are connected. The space within the evaporator surrounding the coils contains a fluid from which heat is extracted by conduction or convection, the heat passing to the refrigerant within the tubing. The fluid surrounding the evaporator tubes may be water or in some cases it may be air or other fluid. As illustrated in FIG. **1** the straight runs of the tubing are horizontal but this is not required and in some cases the straight runs may extend vertically. Also, it is not required that the tubes be U-shaped or utilize U-shaped connectors, as straight lengths of tubing with headers at either end are frequently used.

While the construction so far defined is a refrigeration application of the present invention, the invention is broader and may involve any application in which liquid flowing through the tubing extracts heat from ambient fluid and causes boiling or vaporization of the liquid. FIG. **1**, being schematic in nature, would of course include the familiar shell-and-tube construction of heat exchangers, enclosure **10** representing the shell, while flow to the individual tubes would be provided for by a component known as the channel (symbolized in FIG. **1** by header **12**). While the tubing for refrigeration purposes will normally be between ¼ and 1-½ inch outside diameter, in other applications substantially larger tubing may be employed. For example, tubing having 3 to 4-inch outside diameter may be used in falling-film evaporators.

In refrigeration applications the most efficient results are obtained when a maximum amount of boiling or evaporation takes place within the evaporaor. On the other hand, in some application this condition does not prevail. For example, this would be true in therosyphon reboilers for fractional distillation towers. In this case the circulation is set by the geometrical arrangement and the liquid head available to induce circulation. On the other hand, in some reboilers the fluid to be partially boiled is pumped through the reboiler tubes and hence the circulation rate is tied in with the overall economics as well as the operating stability of the system.

Referring now to FIG. **2** there is shown a length of tubing of the type referred to. This tubing is thin-walled metal tubing such for example as copper having a smooth exterior cylindrical surface **20** and a smooth interior cylindrical surface **22.** The smooth interior cylindrical surface **22** is interrupted by radially inwardly extending ribbing **24** comprising a multiplicity of convolutions extending around the tubing. In the embodiment of the invention illustrated, the ribbing is formed by a single continuous helical rib having a pitch P. While the external surface of the tube may be perfectly smooth, it is convenient to form the internal ribbing by operations applied exteriorly to the tubing, and hence the exterior surface is normally provided with a continuous helical groove **26** which is in registration with the internal ribbing.

In order to make the most efficient use of material and at the same time to provide for economical production, the wall thickness of the tubing will not exceed 0.075 inch and may be substantially smaller. Tests have been performed in which the wall thickness of the tubing is as low as 0.016 inch.

The depth or radial inward extension of the ribbing **24** is illustrated at *d* in FIG. **2** and this dimension is preferably about 1/32 inch, but in any case, between 1/64 inch and 3/64 inch. The tubing illustrates a single continuous groove **26** which of course forms a radially inwardly extending rib **24** in registration therewith. The helix has a pitch P representing the axial advance of a single helical convolution of the groove or rib. Instead of providing a single-start helical rib formation, a multiple-start configuration may be employed and excellent results have been obtained when as many as five sepa-

rate and distinct helical rib and groove formations have been provided, or in other words, a five-start configuration.

One of the possible explanations of the advantage of arranging the inwardly extending rib configuration in a helical arrangement is that a swirling motion is imparted to the partially vaporized material in the tubing as it progresses longitudinally thereof. The result of this swirling movement would be to cause any liquid droplets suspended in the moving vapor to be displaced radially outwardly into contact with the tube wall.

However, it has been found that heat transfer to the material within the tube is markedly superior to the heat transfer effected by a plain tube if the ribbing takes the form of a series of separate and distinct annular external grooves and internal ribs. In this case of course there would be no tendency to impart a bulk swirling motion to the partially vaporized material as it transits the tube; however, it is postulated that localized eddys in the flowing stream in the vicinity of the internal ribs operate to move the liquid droplets to the tube wall where they are readily vaporized.

It will be observed from FIG. 2 that the internally extending rib has in cross-section a smoothly rounded convex crest and that the transverse curvature reverses to blend smoothly into the adjacent smooth cylindrical inner surface of the tubing. This configuration minimizes resistance to flow while at the same time induces a controlled change in direction of flow of material along the portion of the smooth cylindrical internal surface leading up to each rib convolution.

The present invention is limited to arrangements including tubes designed for internal boiling where the problem of different phase proportions creates difficulties having no counterpart in other types of heat transfer tubing such for example as water tube steam condensers.

In the specific embodiment of the invention illustrated in FIG. 2 the P/*d* ratio is approximately **10.** In FIG. 3 there is illustrated a further embodiment of the invention in which the tube **30** is provided at its exterior surface with inwardly extending concave grooves **32** in the form of helical corrugations. The inner surface of the tube is conformably displaced and forms the internal helical rib **34.** In this Figure a single-start helical rib and groove formation is illustrated having a pitch P and the height of the internal rib (or the depth of the internal groove) is again indicated at *d.* In this configuration the P/*d* ratio is approximately **6.**

In FIG. 4 there is illustrated a tube **40** having smooth cylindrical wall sections **42,** internal circular or annular ribs **44,** and conforming external circular or annular grooves **46.** This is similar to the embodiment of FIG. **2,** except that ribs **44** are circular rather than helical.

In FIG. **5,** tube **50** has circular or annular external grooves or corrugations **52** and corresponding internal ribs **54,** corresponding to the helical ribs and grooves of FIG. **3.**

The efficiency of heat exchangers including tubing of the type disclosed herein has been established by extensive testing. The tests have been carried out by a procedure which is described below. The tube to be tested is centrally located inside of a second tube called the envelope tube. The fluid to be boiled is caused to flow through the test tube at a measured rate. A countercurrent flow of water at a measured flow rate is established through the annular space between the test tube and the envelope tube. Provision is made for controlling the temperature of the water entering the tube at a given level, for example, 60°F.

Provision is also made employing a condenser and other accessories to control the level of pressure at the refrigerant-exit end of the test tube. This pressure level sets the boiling temperature of the refrigerant according to its inherent vaporpressure properties. As pressure is increased, the saturated boiling temperature increases. By choice, the pressure level is so set that a desired boiling temperature, for example 32°F., is required. Thus, the heat required for evaporation of the refrigerant is abstracted from the water moving through the annulus by heat flow through the wall of the test tube.

Since the test tube is of substantial length, simulating industrial practice, a substantial pressure drop is associated with the flow of the refrigerant through the tube. The pressure drop of the boiling fluid is, of course, recognized to be intensified over that which would be experienced for the same mass flow of the fluid without boiling.

The pressure-drop encountered with in-tube boiling can be a significant factor, as it not only requires expenditure of energy but it affects the temperature driving force for the transfer of heat. This is so because the boiling temperature is a function of total pressure; and when a fluid is boiling as it passes through a tube, the fluid temperature at the upstream end of the heated section may be several degrees greater than the temperature at the downstream end. In practical situations this effectively lowers the overall driving force for the flow of heat. The test rig described above was fitted with pressure-drop measuring means so that this important factor could be dealt with.

In testing tubing of the type disclosed herein, comparative tests of various tubes were made, utilizing the concentric-tube test rig. By a special testing mode, the various tubes could be fairly evaluated; and an index of effectiveness, or figure of merit, was arrived at which accounted for not only the heat transfer mechanisms but the effect of pressure drop as well. By uniformly fixing the limits of the temperature driving force (water inlet temperature and refrigerant outlet temperature), and by feed-back of pressure drop information as the test progressed, each tube was given the chance to completely evaporate as great a flow of refrigerant as it was capable of boiling. This was a trial and error procedure, since it was necessary to adjust the refrigerant flow and its entering temperature until two conditions were satisfied.

1. The refrigerant entered the heated section as a liquid, but just at its boiling point, and

2. The heated abstracted from the water was just sufficient to completely evaporate the flowing refrigerant without superheating the refrigerant vapor.

Thus, the desired figure of merit was obtained in terms of the pounds per hour of evaporative capacity at the reference conditions. The results of these tests are summarized below and establish that the tubing as disclosed herein is clearly a superior boiling tube as compared to plain tubing and the star-insert tubing heretofore described. It is noted that at the present time the star-insert tubing and plain tubing are the dominant configurations used commercially in direct-expansion water chillers.

TABLE I

Evaporative Capacity of Various Tube Configurations
Conditions: All tubes ¾" OD × .035" wall and of equal length.
Boiling fluid: Freon-12
60° F. water inlet temperature
32° F. refrigerant exit temperature

Run No.	Tube	Tubing Wt. lbs/ft.	Water Flow lbs/hr.	Evaporative Capacity lbs/hr.
700BG4	Plain	.305	5911	372
702H3	Star-insert	.406	6125	505
		to		
701K2		.440	5880	524
723M2	Present Invention	.320	5600	679

In the tests tabulated above the water flow varied slightly from run to run. The apparatus was designed to be insensitive to such variation of water flow, but of course the actual flow was always carefully measured for the purpose of determining the heat duty of the run. If anything, the lower water flow noted above for the tubing of the present invention would be a handicap, and yet the evaporative capacity of the tubing of the present invention clearly and surprisingly overshadowed that of the other tubes.

It is to be noted that the data for two different specimens of star-insert tubes are shown. Such tubes are made up of aluminum shape or star cross-section, inserted into a sheath tube of copper. The amount of "star points" or radial fins may vary, and several modifications of point shape are used. In the manufacture of star-insert tubes every effort is made to secure a good mechanical bond between copper and aluminum by a sinking operation to minimize any thermal resistance at the interface. Tubing of this general type dominates the DX-water chiller field today, although plain tubes are also used.

An important advantage of the tubing in accordance with the present invention is that there is no insert, and hence no concern over the bonding problem or elimination of thermal resistance at the interface. From a caparative value of tubing weight per foot, it will be observed that the tubing disclosed herein enables a very substantial saving of metal as compared to the star-insert tube, while at the same time provides specifically greater evaporative capacity. It will be noted from the above table that the evaporative capacity of tubing of the present invention is nearly double that of plain tubing.

In practice, the refrigerant enters the evaporator with a substantial part thereof in liquid phase, a typical ratio of liquid to vapor refrigerant being 4/1. The expression "substantial liquid phase" is intended to signify such predominance of liquid refrigerant.

What we claim as our invention is:

1. The method of boiling a hydrocarbon or substituted hydrocarbon liquid which comprises causing it to flow longitudinally through metal tubing having its exterior surface in contact with ambient fluid at a temperature above the boiling point of the liquid at the pressure range existing within the tubing, the tubing having its interior substantially unobstructed except for surface configuration, the interior surface of said tubing being provided with radially inwardly extending ribbing, said ribbing comprising a multiplicity of rib convolutions extending around the tubing, the axial pitch P of adjacent convolutions being not greater than ¾ inch, the depth *d* or radial extension greater than ¾ inch, the depth *d* or radial extension of said ribbing being between 1/64 inch and 3/64 inch, the ratio of pitch to depth of convolutions P/*d* being between 5 and 25, said tubing having a wall of substantially uniform thickness, the exterior of said tubing having a multiplicity of groove convolutions which are disposed opposite to the rib convolutions at the interior of said tubing, are of a depth substantially equal to the depth or radial extension of said ribbing, and conform thereto.

2. The method as defined in claim **1** in which the tubing has a wall thickness of not more than 0.075 inch.

3. The method as defined in claim **2** in which the wall of the tubing intermediate said rib and groove convolutions has a smooth cylindrical surface.

4. The method as defined in claim **1** in which the ribbing convolutions are helical.

5. The method as defined in claim **4**, in which said ribbing consists of a single helical rib.

6. The method as defined in claim **4**, in which the ribbing consists of a plurality of helical ribs.

7. The method as defined in claim **1** in which the ribbing convolutions consist of a multiplicity of separate annular ribs.

8. The method as defined in claim **2** in which the ribbing convolutions are helical.

9. The method as defined in claim **2** in which the ribbing convolutions consist of a multiplicity of separate annular ribs.

10. The method as defined in claim **1** in which the outside diameter of the tubing is ¾ inch to 1-½ inch.

11. The method as defined in claim **10** in which the tubing has a wall thickness of not more than 0.075 inch.

12. The method as defined in claim **10** in which the ribbing convolutions are helical.

13. The method as defined in claim **1** in which the liquid is a halogenated hydrocarbon refrigerant such as Freon.

14. The method as defined in claim **1** which comprises controlling the flow to introduce the hydrocarbon or substituted hydrocarbon into the tubing substantially in liquid phase and effecting substantially complete vaporization within the tubing to cause exit of the hydrocarbon from the tubing substantially in vapor phase.

15. Evaporator construction comprising an enclosure, metal heat exchange tubing in said enclosure for receiving a hydrocarbon or substituted hydrocarbon refrigerant in substantially liquid phase at one end and for discharging the refrigerant in substantially vapor phase at the other, the exerior surface of said tubing being in heat exchange relation with a fluid transiting said enclosure and giving up heat to the refrigerant to vaporize substantially all of the refrigerant, the interior of said tubing being substantially unobstructed except for surface configuration, the interior surface of said tubing being provided with radially inwardly extending ribbing, said ribbing comprising a multiplicity of convolutions extending around the tubing, the axial pitch P of adjacent convolutions being not greater than ¾ inch, the depth *d* or radial extension of said ribbing being between 1/64 inch and 3/64 inch, the ratio of pitch to depth of convolutions P/*d* being between 5 and 25, said tubing having a wall of substantially uniform thickness, the exterior of said tubing having a multiplicity of

groove convolutions which are disposed opposite to the rib convolutions at the interior of said tubing, are of a depth substantially equal to the depth of radial extension of said ribbing, and conform thereto.

16. The construction as defined in claim **15** in which said tubing has a wall thickness of not more than 0.075 inch.

17. The construction as defined in claim **16** in which the wall of said tubing intermediate said rib and groove convolutions has a smooth cylindrical surface.

18. The construction as defined in claim **15,** in which said ribbing convolutions are helical.

19. The construction as defined in claim **18** in which said ribbing consists of a single helical rib.

20. The construction as defined in claim **18** in which said ribbing consists of a plurality of helical ribs.

21. The construction as defined in claim **20** in which said ribbing convolutions consists of a multiplicity of separate annular ribs.

22. The construction as defined in claim **16** in which said ribbing convolutions are helical.

23. The construction as defined in claim **16,** in which said ribbing convolutions consist of a multiplicity of separate annular ribs.

24. The construction as defined in claim **15** in which the outside diameter of said tubing is ¼ inch to 1½ inch.

25. The construction as defined in claim **24** in which said tubing has a wall thickness of not more than 0.075 inch.

26. The construction as defined in claim **24** in which said ribbing convolutions are helical.

* * * * *