

[54] **METHOD OF MODIFYING A FINNED TUBE FOR BOILING ENHANCEMENT**

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[52] U.S. Cl. **72/68, 29/157.3 AH, 29/157.3 B, 72/367, 165/133**
[51] Int. Cl. **B21b 15/00**
[58] Field of Search **29/157.3 A, 157.3 AH, 29/157.3 B; 165/133, 181, 184; 72/68, 367**

[56] **References Cited**
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3,326,283 6/1967 Ware 165/184 X

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1,533,025 7/1968 France 165/181
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Primary Examiner—Charles W. Lanham
Assistant Examiner—D. C. Reiley, III
Attorney—Charles R. McKinley et al.

[57] **ABSTRACT**
Tubing having circumferentially extending fins, either annular or helical, is modified by forming or bending the fins transversely so that the tip of each fin convolution is closely adjacent to a portion of the next adjacent fin convolution providing small continuous or discrete gaps of predetermined and controlled average size into substantially confined spaces between adjacent fin convolutions.

16 Claims, 12 Drawing Figures

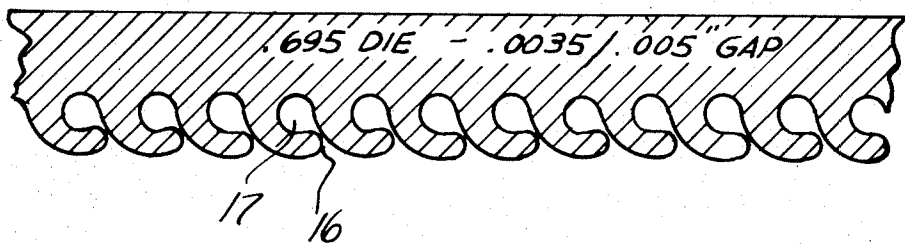


FIG. 1

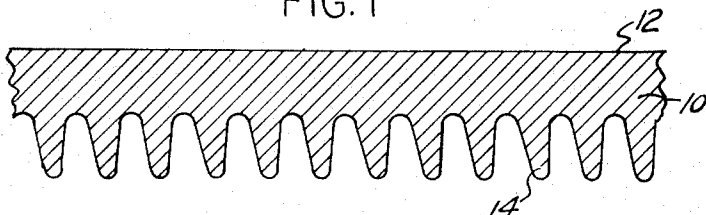


FIG. 2

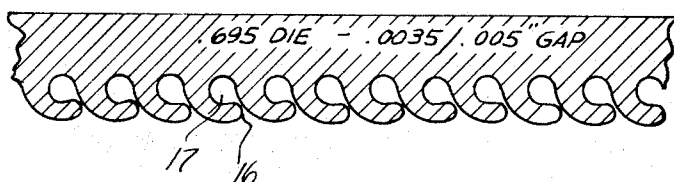


FIG. 3

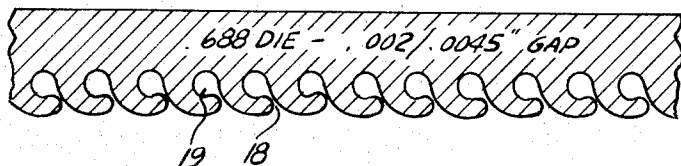


FIG. 4

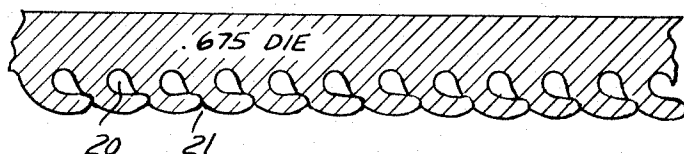


FIG. 12

BOILING CURVES - 26 FIN CONFIGURATIONS
REFRIGERANT - 11 @ 1 ATMOSPHERE

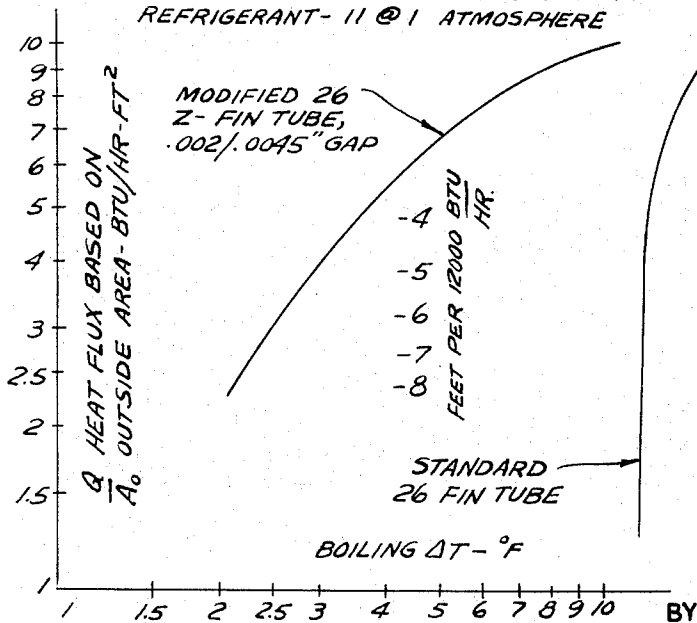


FIG. 6

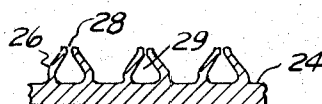


FIG. 7

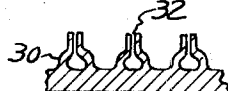


FIG. 8

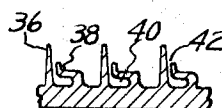


FIG. 9



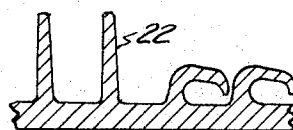
FIG. 10



FIG. 11



FIG. 5



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METHOD OF MODIFYING A FINNED TUBE FOR BOILING ENHANCEMENT

BRIEF SUMMARY OF THE DISCLOSURE

It has been found that heat transfer tubes adapted to transfer heat from a fluid flowing within the tube to a liquid in contact with the outer surface of the tube for the purpose of boiling the liquid, have a substantially increased efficiency in boiling the liquid, when they are provided with a porous surface having a multiplicity of substantially confined spaces into which the liquid may flow. These spaces have substantially restricted ports or passages providing for flow of liquid into the spaces and for escape of vapor from the substantially confined spaces.

The present disclosure relates to tubes in which heat transfer fins of usual shape are provided on the outer surface thereof. These fins may be separate annular fins or they may be provided to extend helically on the outer surface of the tube. In the latter case the fin convolutions may be in the form of a single helix or two or three or more separate but interleaved helical fins may be provided.

Preferably, the fins are formed on the tube by well known processes such for example as disclosed in Locke U.S. Pat. No. 1,865,575. In finned tubing of this type the fins are integral with the material of the tube wall and are formed to extend outwardly from the tube wall by rolling operations. As initially produced, each fin convolution extends substantially radially outwardly from the tube, whether provided in the form of single annular convolutions or a multiplicity of helical convolutions. The fins are outwardly tapered and have a height which substantially exceeds the average fin thickness as well as the average spacing between adjacent fin convolutions.

In accordance with the present disclosure, these fins are bent or formed so that the crest of some or all of the fins is closely adjacent to the surface of the next adjacent fin convolution with the result that there is provided a confined space of substantial size having a port or passage leading outwardly therefrom defined between the tip of one fin convolution and the side of the next adjacent convolution.

This bending over of the fins may be accomplished in different ways, some of which are applicable to single-start fins and others of which are designed for use with different multiple-start fins. In the simplest form of the invention the finned tubing is simply drawn through a die which is dimensioned to bend the fin convolutions over into required position. Best results have been obtained when the dimensions and configuration of the die is such that the crest of each fin convolution is not only bent over into contact with a surface of the next adjacent fin convolution, but is forced beyond the position of initial contact. When the die dimensions are properly controlled the bent over fins upon emergence from the die, spring back out of contact with the adjacent surface and remain at a predetermined substantially accurately controlled spacing therefrom. In other forms of the invention the fins are reformed by rolls or dies during or subsequent to the finning operation.

It will be appreciated that where the fins are in the form of annular convolutions, the confined space is annular in shape. Where the convolutions are in the form of a single-start fin extending helically from the tube, the confined space is in the form of a single elongated

helically disposed space. Similarly, where multiple-helix fins are provided, separate elongated helically disposed confined spaces result.

It will further be appreciated that the closure provided by bending over the fins does not produce a perfectly accurate continuous gap between tee crests of the bent-over fin convolutions, but instead, there may be some variation such for example as areas in which the fin tips remain in contact with the surface of the adjacent convolution and are spaced therefrom at varying intervals. The control of the spacing may accordingly be considered as providing an average spacing rather than a perfectly accurate continuous spacing.

Tests of operating efficiency of the tubing modified for boiling enhancement indicate that the average width of the space or gap between the crests of a fin convolution and the adjacent surface of the next convolution should be up to 0.007 inch. The maximum improvement in boiling efficiency is noted where the gap does not exceed 0.005 inch.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an enlarged fragmentary section through a wall of a finned tube.

FIGS. 2-4 are sectional views showing the configuration of fins bent over after passage through differently dimensioned dies.

FIG. 5 is a fragmentary sectional view illustrating a somewhat different embodiment of the disclosure.

FIGS. 6-9 are fragmentary sectional views illustrating fin configurations for double-finned or double-start finned tubing.

FIG. 10 is a fragmentary sectional view showing one embodiment of fin modification.

FIG. 11 is a view similar to FIG. 10 showing another embodiment of the disclosure.

FIG. 12 is a graph showing comparative boiling efficiencies of a plain tube and a tube made in accordance with the present disclosure.

DETAILED DESCRIPTION

It has been found that porous finishes, points or small gaps leading to partially confined spaces generally enhance the boiling capacity of a surface. Recent examples of such enhancement noted in the patent literature are tip indented finned tubing shown in U.S. Pat. No. 3,487,670, a wire wound finned tube shown in U.S. Pat. No. 3,521,708, and microscopically grooved surfaces shown in U.S. Pat. Nos. 3,454,081 and 3,496,752.

In accordance with the present invention, conventional integrally finned tubing is modified to enhance boiling by bending the tips of the fin convolutions over so that a small gap of controlled size is formed between the tip of one convolution and the side or other adjacent surface of the next fin convolution. From the foregoing it will be apparent that the small gap of controlled size leads to a substantially enlarged chamber or space which extends around the tube in the form of one or more convolutions depending upon whether the fins are initially annular or helical.

In the first place, it has been found that by methods which will subsequently be described, predictable small gaps up to 0.007 inch may be produced by a simple drawing operation of the finned tube through a die having a circular cross-section and dimensioned to bend the fin convolutions as required.

Further investigation has indicated that substantial improvement in boiling efficiency is obtained when the gaps as above described, have an average width up to 0.007 inch with the maximum improvement where gap widths are 0.005 inch or less.

While the simplest method of bending the fins to produce the required spacing is to draw the finned tube through the die, other methods are of course available and may be necessary when the procedure is applied to multiple-start fins in which different formation is imparted to the separate fins.

Referring now to FIG. 1, there is shown in enlargement a fragmentary section through the wall 10 of a finned tube provided with a multiplicity of fins 14 which may, for example, be separate and independent annular fins, or provided in helical arrangement with one or more separate helical fins. The fin of the actual tube illustrated in FIG. 1 was a single helix; however, tubes shown in FIGS. 2, 3 and 4 could also be made from multiple-helix fin tube.

In FIG. 2 there is illustrated the resulting deformation of the fin after the tube (which has an initial outside diameter of 0.740 inch) was drawn through a die of circular cross-section having an internal diameter of 0.695 inch. The average space as indicated at 16, between the crests of the fin convolution and the adjacent side surface of the next adjacent fin convolution was found to be 0.0035 - 0.0050 inch. An inspection of this Figure indicates that there is thus provided a continuous substantially closed space or chamber 17 through which liquid in contact with the finned surface may enter. It will of course further be apparent that where the fins 14 are in the form of separate annular fins, these enclosed spaces or chambers 17 are annular and are equal in number to the number of fins. Where the fin is provided in the form of a single helical fin, it will be apparent that the configuration illustrated in FIG. 2 results in a single helically extending enclosed space or chamber. Similarly, where two or three separate but interleaved helical fins are provided, the enclosed spaces or chambers are helical and are equal in number to the number of separate fins.

In FIG. 3 there is illustrated the fin configuration when the same finned tube shown in FIG. 1 was drawn through a die having an internal diameter of 0.688 inch. In this case the gap between the crests of the fin convolutions and the adjacent side surface of the next adjacent convolution was found to have an average width of 0.0020 - 0.0045 inch. In this Figure the location of the gap or gaps is indicated at 18. The tube formation illustrated results in the essentially enclosed space or chamber 19 which may be circular or helical as described in connection with FIG. 2.

In FIG. 4 there is illustrated the fin configuration when the same tube is drawn through a die having an internal diameter of 0.675 inch. In this case it was found that the crests of the fin convolution were bent over and deformed the material of the adjacent convolution as indicated at 21, so that no gap was visible to the unaided eye. However, a reproducible finite gap is visible when microscopically examined.

The three configurations of tube described in the foregoing are for the purpose of indicating that an accurate control of the average gap between the crests of the tube convolutions and the adjacent side wall of the adjacent convolution can be predetermined and main-

tained by selecting the appropriate die through which the finned tube is drawn.

Tubing having the configuration illustrated in FIGS. 2, 3 and 4 has been subjected to boiling tests and it has been found that for substantial enhancement of boiling, the gap into the enclosed annular or helical space should have an average width of 0.007 inch or less with the maximum improvement occurring where the gap is 0.005 inch or less.

The variable parameters which influence the efficiency of the disclosed construction in enhancing boiling are number of fins per inch of tubing and gap to trapped volume ratio, as well as gap width. In accordance with the present invention, the number of fins per inch will not exceed 40.

Tubing generally of the type illustrated in FIGS. 2, 3 and 4 was subjected to boiling tests in which boiling ΔT (which for this purpose may be considered as the difference between the average temperature of the tube wall metal and the boiling temperature of the fluid outside the tube) was determined for different heat flux values based on outside area - BTU/Hr-Ft².

When the tubing was tested at 4,000 BTU/Hr-Ft², the test results were as tabulated:

	fins/inch	Average Gap	ΔT
1	19	0.001 - 0.0016"	5.3° F.
2	19	0.0035 - 0.0040"	5.3° F.
3	19	(standard fins)	11.5° F.
4	26	less than 0.001"	3.0° F.
5	26	0.002 - 0.0045"	3.0° F.
6	26	(standard fins)	12.0° F.

It is thus seen that the 19-fin tubing having the fins bent over to define restricted substantially enclosed spaces represents an improvement over the unmodified finned tube in the required ΔT of about 54 percent.

Similarly, the modified 26-fin tubing showed an improvement of about 75 percent in the boiling ΔT over unmodified tubing.

The foregoing tests also establish the superiority of the 26-fin modified tube over the 19-fin modified tube, in a reduction from 5.3° F. for the 19-fin tube to 3.0° F. for the 26-fin tube.

FIG. 12 graphically illustrates the enhancement in boiling which follows bending or forming the fins of a 26-fin tube, such as seen in FIG. 1, to the form shown in FIG. 3. In this tube, where the gap between the crests of the fins and the side surface of the adjacent fin convolution has an average dimension of 0.002 - 0.045 inch. From this graph, it will be noted that at 6 feet per ton, the boiling ΔT for 26-fin standard tube is 12° F. The finned tubing modified in accordance with the present invention is referred to as Z-fin tube, and for the 26 Z-fin tube illustrated in FIG. 3, the boiling ΔT is 2.5° F. for an improvement of about 80 percent in the boiling film temperature drop.

FIG. 5 illustrates another fin configuration for a single helix tube when formed by a process other than drawing through a circular die. In this Figure no attempt is made to illustrate a gap between the crest portion of a finned convolution and the side of the next adjacent convolution, but it is to be understood that an average gap of less than 0.007 inch will be provided.

Referring now to FIG. 6 there is illustrated a modified finned tube 24 produced from a double or two-start fin. In this case each of the fins 26 is inclined towards each other so that a gap of controlled dimensions is provided at 28 between the crests of the fins. With this arrangement a helical substantially enclosed space or chamber 29 is formed.

In FIG. 7 the fins 30 are bent toward each other in such a way as to define a gap 32 therebetween, this gap appearing between spaced apart fin portions which are relatively flat in cross-section. With this configuration it will be apparent that the confined space 34 is essentially smaller than the space 29 provided between the fins in FIG. 6.

In FIG. 8 an arrangement is illustrated in which one of the fins 36 is not modified and the other fin 38 is bent towards the unmodified fin as illustrated so as to produce the helical substantially enclosed space or chamber 40 and the controlled restricted gap or opening 42.

Referring now to FIG. 9 there is illustrated an arrangement generally similar to that shown in FIG. 6 except that the separate fins 44 and 46 are curved and inclined towards each other to produce a substantially circular cross-section enclosed space or chamber 48 and the narrow restricted gap 50.

The tubing of FIGS. 10 and 11 is produced from finned tubing have three interleaved helical fins. In FIG. 10 the fins 62 and 64 are illustrated as bent toward the intermediate unmodified fin 63 so as to define the substantially enclosed spaces or chambers 66.

In FIG. 11 the fins, here designated 62a and 64a, are bent in a different manner toward the intermediate fin 63a to define the substantially enclosed spaces or chambers 66a.

It will be understood that in the embodiments of the invention illustrated in FIGS. 6 to 11, the modification of the normally outwardly or radially extending fins is provided progressively along the helical paths occupied by the fins. For this reason the simple embodiment of the invention illustrated in FIGS. 2-5 is preferred, since the fins are given the required configuration by the simple act of drawing the finned tube through the appropriate circular die.

While the present disclosure is broadly applicable to enhancement of boiling in any liquid, it is particularly advantageous in the art of refrigeration, where the boiling or vaporization is of a refrigerant.

The finned tube as illustrated in FIG. 1, prior to bending over the fins, has in a typical example the following dimensions: The internal diameter of the tube is 0.557 inch and the wall thickness, measured from the inside of the tube to the bottom of the space between adjacent fins is 0.035 inch. The fins have a radial dimension of 0.057 inch and are provided at a frequency of about 26 fins per inch, giving a pitch from fin convolution to fin convolution of approximately 0.038 inch. The individual fins have a thickness at the base of approximately 0.0165 inch and at the tip or crest of 0.0075 inch. This gives an average width of approximately 0.012 inch. The space between adjacent fins increases from approximately 0.021 inch adjacent the roots of the fins to approximately 0.0305 inch adjacent the crests.

The finned tubing illustrated in FIG. 1 has an approximate outside diameter, before the bending of the fins, of 0.740 inch. The configuration illustrated in FIG. 2

results from drawing this tube through a die having an internal diameter of 0.695 inch and produces a gap 16 into the substantially enclosed space 17 of 0.0035 - 0.0050 inch.

The configuration illustrated in FIG. 3 results from drawing the tubing illustrated in FIG. 1 through a die having an internal diameter of 0.688 inch, which produced a gap 18 communicating with the space 19 of 0.002 - 0.0045 inch.

The configuration illustrated in FIG. 4 resulted from drawing the tubing of FIG. 1 through a die having an internal diameter of 0.675 inch. In this operation the crests of each fin convolution were bent over into contact with the next adjacent fin convolution with such force as to provide deformation of the material, as has been previously described.

The dimensions of the fins in relationship to spacing are of course of critical nature since this determines the general shape and dimensions of space which is enclosed when the outer portion of each fin convolution is bent over into close proximity to the adjacent wall portion of the adjacent fin convolution, to provide the restricted opening into the substantially enclosed space. For uniform and readily controllable conditions, the fin height should be greater than the spacing between adjacent fins and the fin tip thickness should be substantially less than the fin thickness at the root. With this configuration the fins are readily bent and can be formed to touch the adjacent fin, and at the same time enclose a substantial volumetric space with accurate control of the gap providing for ingress of liquid and egress of vapor from the substantially enclosed space.

Bending of the fins is facilitated where the height of the fin is substantially greater than the average width, as for example, not less than twice the average width.

In all cases the fins are formed by rolling up material from the outer wall of the tubing, so that the fins originally extend generally perpendicular to the surface from which they were displaced, and portions thereof extend generally parallel to corresponding portions of adjacent fin convolutions.

Since the fins are originally produced by a rolling operation, the average spacing between adjacent fin portions is greater than the average thickness of the fins. This results inherently in the production of substantially enclosed spaces or chambers, after the outer portions of the fins are bent over, which are of quite substantial size. At the same time, the openings into the substantially enclosed spaces may be very restricted, by bending the outer portions of tube convolutions into very close spacing from the side surface of adjacent fin portions.

What I claim as my invention is:

1. The method of making tubing modified for the enhancement of boiling of liquid in contact with the exterior surface thereof which comprises rolling up fin convolutions out of the material at the exterior of the tubing with each convolution extending generally radially outwardly of the tubing parallel to and spaced substantially from adjacent convolutions, and thereafter drawing the finned tube through a die having a throat with a minimum transverse dimension smaller than the outside diameter of the original fin convolutions to form the outer portions of fin convolutions completely around the finned tube into proximity to a side of adjacent fin convolutions to define therewith a substantially

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enclosed space extending around the tubing and a restricted opening into such space.

2. The method as defined in claim 1 which comprises using a die dimensioned to deform the outer portion of each fin convolution into solid contact with the surface of the adjacent convolution, and to provide predetermined width of the restricted opening into the space by spring-back of the outer fin convolution portion.

3. The method as defined in claim 2 which comprises using a die dimensioned to cause the outer portion of each fin convolution to deform the portion of the next adjacent fin contacted thereby as the tubing passes through the die.

4. The method as defined in claim 1 which comprises the initial step of forming the fin convolutions to extend helically around the tubing.

5. The method as defined in claim 1 in which the height of each fin prior to bending is at least twice the average thickness thereof.

6. The method as defined in claim 1 in which the average spacing between adjacent fin convolutions substantially exceeds the average thickness of each fin.

7. The method as defined in claim 5 in which the average spacing between adjacent fin convolutions sub-

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stantially exceeds the average thickness of each fin.

8. The method as defined in claim 1 in which the throat of the die is dimensioned to form the outer portions of the fin convolutions into such proximity to the side of adjacent fins as to produce a gap having an average width of not more than 0.007 inch.

9. The method as defined in claim 8 in which the average width of the gap is not more than 0.005 inch.

10. The method as defined in claim 8 in which the average width of the gap is between 0.0035 - 0.0050 inch.

11. The method as defined in claim 5 in which the average width of gap is not more than 0.007 inch.

12. The method as defined in claim 5 in which the average width of gap is not more than 0.005 inch.

13. The method as defined in claim 5 in which the average width of gap is between 0.0035 - 0.0050 inch.

14. The method as defined in claim 6 in which the average width of gap is not more than 0.007 inch.

15. The method as defined in claim 6 in which the average width of gap is not more than 0.005 inch.

16. The method as defined in claim 6 in which the average width of gap is between 0.0035 - 0.0050 inch.

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