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(54) **Heat transfer boiling surface.**

(57) A heat transfer device comprises a base wall of heat conductive material, a plurality of spaced apart fins formed integrally with the surface of the base wall at 30 to 40 fins per inch, and a plurality of indentations formed in the peripheral edge of the fins by a diamond knurling tool forming two series of parallel threads in the range of 40-80 threads per inch intersecting each other at an angle of 10 to 80 degrees.

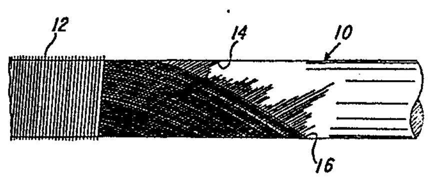

Fig. 1

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HEAT TRANSFER BOILING SURFACE

This invention relates to a heat transfer device, and more particularly to a heat transfer tube having an improved nucleate boiling surface.

One mode of heat transfer from a surface to a fluid in contact with such surface is nucleate boiling. This phenomenon is well known and consists in that, during boiling, many vapour bubbles are generated on the heat transfer surface from active areas known as nucleation sites and rise to the surface of the liquid. This creates agitation and increases heat transfer. It is also known that these vapour bubbles are more readily formed at surface irregularities. Therefore, in order to obtain a large heat transfer coefficient, it is generally recognized to roughen the surface of heat transfer devices to create as many nucleation sites as possible. Up to now, various methods of forming nucleation sites have been proposed. U.S. Patent No. 3,326,283 teaches the idea of knurling an already finned tube. U.S. Patent No. 3,454,081 teaches a method for increasing the number of nucleation sites in which ridges formed by scoring are deformed by a subsequent knurling operation to create partially enclosed and connected subsurface cavities for vapour entrapment so as to promote nucleate boiling. U.S. Patent No. 3,683,656 teaches another method of increasing the number of nucleation sites by partially bending the fins of a finned tube to form cavities. U.S. Patent No. 3,893,233 teaches the idea of first knurling a smooth tube with a diamond pattern and then subjecting the knurled tube to a finning operation to form small splits of a controlled geometry and depth which become efficient nucleation sites for boiling enhancement.

Applicant has found that an improved heat transfer can be obtained by a method similar to the one disclosed in U.S. Patent No. 3,326,283 mentioned above. In the prior art patent, the nucleation sites were formed by knurling a finned tube in such a way as to create a regular pattern of 14 to 33 teeth per circumferential inch in each fin. The patentee specifically points out that at less than 14 teeth per circumferential inch a low increase in heat transfer is obtained and that at a density higher that 33 teeth per circumferential inch, an irregular pattern is formed due to interference between the knurling tools and that the heat transfer is reduced.

Applicant has surprisingly found that an increase in heat transfer of 200 to 300% over that of a smooth tube may be obtained by performing an improved knurling operation on a finned tube.

The heat transfer device, in accordance with the invention, comprises a base wall of heat conductive material, a plurality of spaced apart fins formed integrally with the surface of the base wall at about 30 to 40 fins per inch, and a plurality of indentations formed in the peripheral edge of said fins by a diamond knurling tool forming two series of parallel threads in the range of 40-80 threads per inch intersecting each other at an angle of 10 to 80 degrees, preferably about 60 degrees.

The base wall is preferably a tube and the indentations are formed as a knurled diamond pattern around the outer periphery of the tube.

The height of the fin is preferably in the range of .025 to .040 inch and the depth of the indentations in the range of .012 to .020 inch.

The invention will now be disclosed, by way of example, with reference to the accompanying drawings in which:

Figure 1 illustrates a finned tube upon which has been formed a finning operation as a first step in the making of a heat transfer boiling surface, followed by a diamond knurling operation;

Figure 2 is an enlarged fragmentary longitudinal section through a portion of the tube of figure 1 upon which both the finning and knurling operations in accordance with the invention have been performed; and

Figure 3 is a graphical presentation of the heat flux for the tubes tested over a range of Log Mean Temperature Difference.

Referring to Figure 1, there is shown a tube 10 having integrally formed external fins 12. The fins are preferably arranged in configuration from 30 to 40 fins per inch (FPI) and have a height of about .032 inch. Such tube is subsequently subjected to a knurling operation ation known as diamond knurling wherein two series of parallel threads 14 and 16 in the range of 40-80 threads per inch (TPI) intersecting each other at an angle of about 60° are formed on the fins at a depth of about .016 inch. This operation forms a plurality of subsurface cavities 18 with restricted openings 20 to the outer surface of the tube as illustrated in Figure 2 of the drawings.

Heat transfer tests were performed on five tubes hereinafter designated C-0 to C-4. All tubes had internal smooth surfaces. Tube C-0 had an external smooth surface. Tube C-1 was finned at 30 FPI and knurled at 80 TPI. Tube C-2 was finned at 40 FPI and knurled at 40 TPI. Tube C-3 was finned at 40 FPI and knurled at 80 TPI. Finally, tube C-4 was finned at 30 FPI and knurled at 30 TPI.

The apparatus used for making the tests is an apparatus boiling refrigerant R-11 such as disclosed in a paper by T. C. Carnavos entitled "An Experimental Study: Condensing R-11 on Augmented Tubes" presented at the joint ASME/AICHE National Heat Transfer Conference, Orlando, Florida, July 27-30, 1980. The apparatus consisted of an insulated rectangular shell having within the shell a single condensing tube in the upper portion and a single boiling tube in the lower portion for vapour generation. The tested boiling tubes were 3/4" nominal and approximately 52" long. Hot water flowed in a closed loop through a calibrated 250 mm rotameter and the boiling tube, and returned to a Variac controlled 9kw hot water heater for reheating. Cold water flowed in a closed loop through a calibrated 600 mm rotameter and condensing tube, and returned to a holding tank. A pump took water from the tank, put it through a shell and tube heat exchanger then back to the tank. City water was used to cool the test water in the heat exchanger. Temperature measurements were made with precision glass stem mercury thermometers having 0.056°C minimum graduations and 76 mm immersion. All thermometers were properly immersed and their positions were switched in stream during data acquisition to minimize temperature difference inaccuracy for heat balance determination. A mercury manometer was used to measure shell pressure to determine shell temperature.

Data acquisition was conducted under steady state conditions. Heat balances were made between the waterside heat loads of the boiling and condensing tubes and fell predominantly in the range of ±10%. Average data values were used in the analysis. The tubeside mass flux was held constant at 1540 kg/sec m^2 in order to make direct comparisons of overall heat transfer capability meaningful. The magnitude of 1540 kg/sec m^2 of nominal flow area represents the approximate lower end commonly used in commercial practice. In addition, larger temperature differences resulted for closer heat balances. The heat loads Q_b (boiling) and Q_c (condensing) were calculated as follows:

$$Q_b = W_b\, c_p\, (T_{bi} - T_{bo})$$

$$Q_c = W_c\, c_p\, (T_{co} - T_{ci})$$

where

W_b (boiling tube) and W_c (condensing tube) = Flow rate - kg/hr

C_p = Specific heat - k J/kg°C

T_{bi}, T_{bo} (inlet, outlet boiling tube) = Temperature - °C

T_{ci}, T_{co} (inlet, outlet condensing tube) =Temperature -°C

The heat flux Q was calculated by:

$$\frac{Q}{A_n\ (L)} = \frac{Q_b + Q_c}{2\ A_n\ (L)}$$

where Q_b and Q_c are defined above and

A_n = Nominal Heat Transfer Area in m^2 based on nominal outside diameter of tube over augmentation

L = Length of tube - m

The Log Mean Temperature Difference (LMTD) was calculated as follows:

$$LMTD = \frac{T_{bi} - T_{bo}}{\ln\left[(T_{bi} - T_b)/(T_{bo} - T_b)\right]}$$

where T_{bo}, T_{bi} are as defined above and T_b is the boiling pool temperature in °C.

Figure 3 provides the graphical presentation of Heat Flux for all the tube tested over the Log Mean Temperature Difference (LMTD). Tube C-3 having the geometry 40 FPI/80TPI exhibited the highest overall heat flux, some 200 to 300% above smooth tube C-0, across a broad LMTD range. The C-3 tube is especially a good performer in the lower LMTD range, where operation is most prevalent for these types of augmented boiling tubes. Tubes C-1 and C-2 having the geometry 30 FPI/ 80 TPI and 40 FPI/40 TPI, respectively, exhibited a heat flux slightly lower than C-3, more particularly at the lower LMTD but their performance is still much better than smooth tube C-0. Tube C-4 is a finned tube which was knurled at 30 TPI and which contains about the same number of nucleation sites per unit area as the tubes disclosed in U.S. Patent No. 3,326,283. It will be noted that the performance of the tube C-4 is much lower than that of tubes C-1, C-2 and C-3 which are made in accordance with the present invention, that is knurled at 40-80 FPI. It will thus be seen from the above that the performance gains obtained with the finned tubes knurled at 40-80 FPI are very substantial, not only over a smooth tube but also over the tubes disclosed in the above U.S. Patent No. 3,326,283.

CLAIMS

1. A heat transfer device comprising a base wall of heat conductive material, a plurality of spaced apart fins formed integrally with the surface of said base wall at 30 to 40 fins per inch, and a plurality of indentations formed in the peripheral edge of said fins by a diamond knurling tool forming two series of parallel threads in the range of 40-80 threads per inch intersecting each other at an angle of 10 to 80 degrees.

2. A heat transfer device as defined in claim 1, wherein the angle between the two series of parallel threads is about 60 degrees.

3. A heat transfer device as defined in claim 1, wherein said base wall is a tube and wherein said indentations are formed as a knurled diamond pattern around the outside periphery of said tube.

4. A heat transfer device as defined in claim 1 2 or 3 wherein the height of the fins is in the range of .025 to .040 inch and the depth of the indentations in the range of .012 to .020 inch.

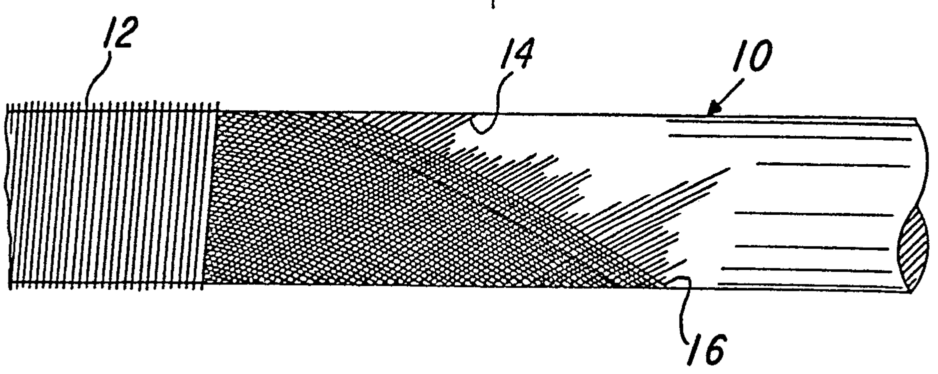


Fig. 1

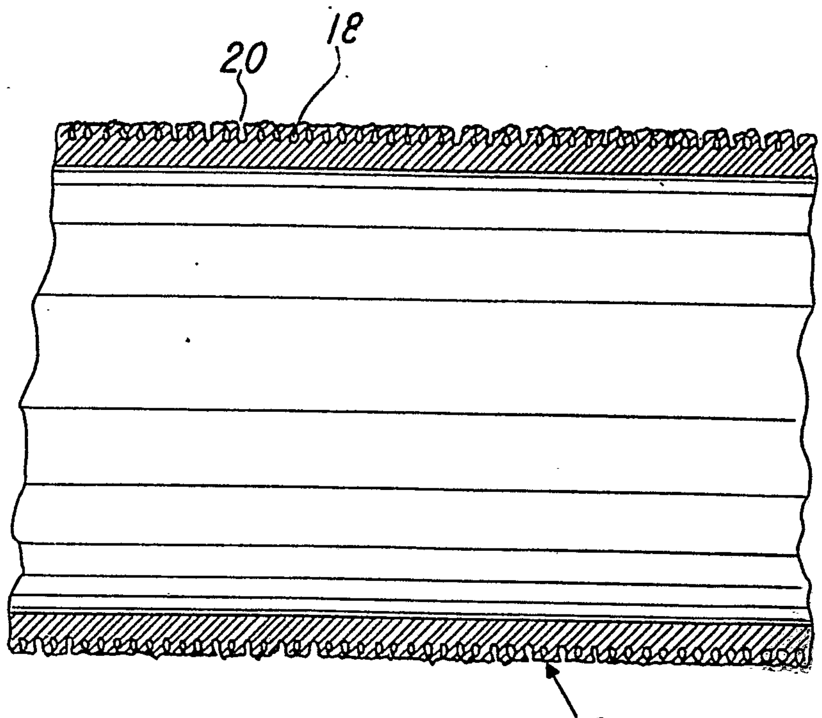
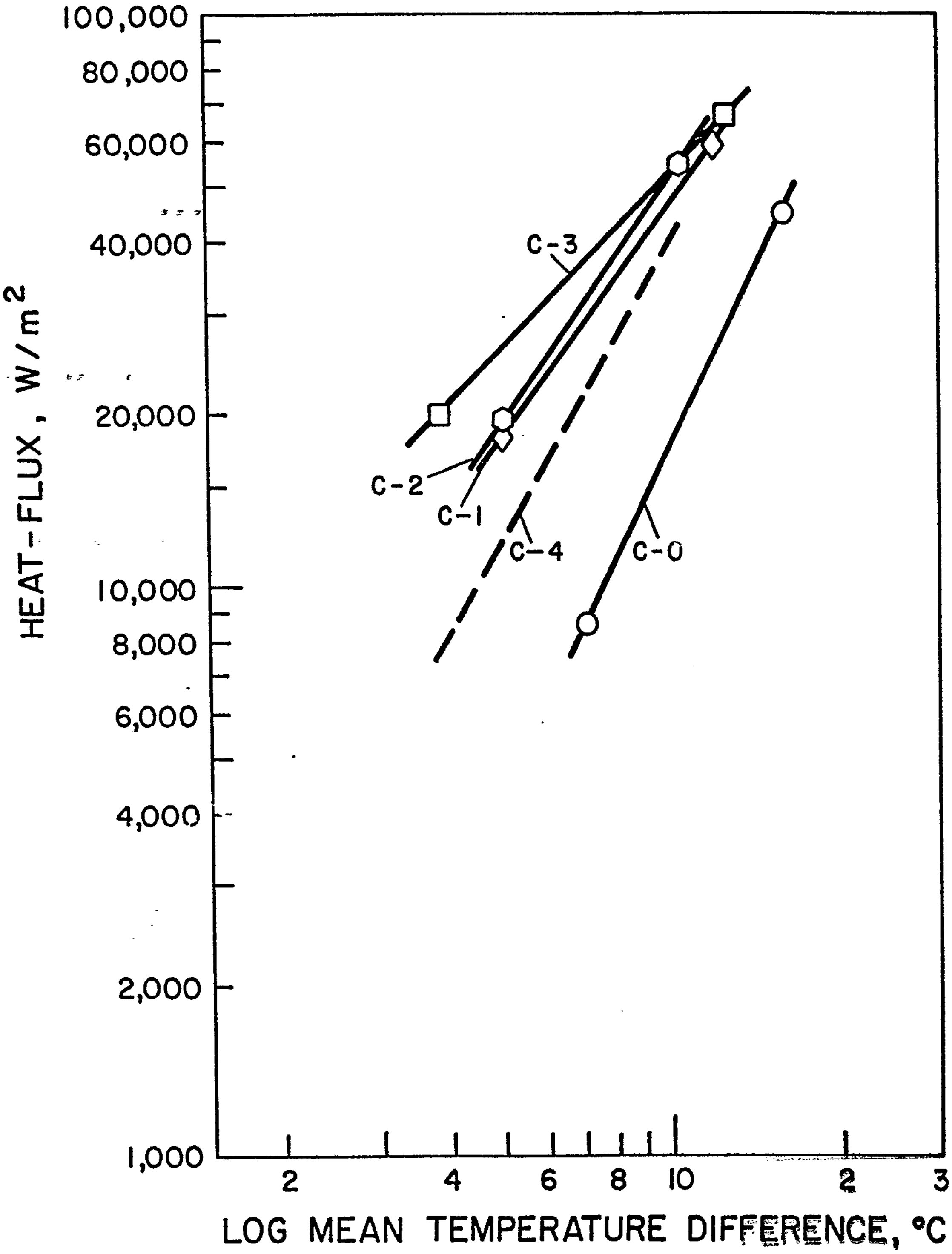


Fig. 2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10,000
8,000
6,000
4,000
2,000
1,000
HEAT-FLUX, W/m2
C-3
C-2
C-1
C-4
C-0
2
4
6
8
10
2
3
LOG MEAN TEMPERATURE DIFFERENCE, °C

Fig. 3