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Degroote

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[54] **METHOD OF METALLURGICALLY BONDING A INTERNALLY FINNED HEAT EXCHANGE STRUCTURE**

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[51] **Int. Cl.**..... **B21d 53/02**

[58] **Field of Search**..... 29/157.3 R, 157.3 A, 490, 29/DIG. 4; 113/118 R, 118 A

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Assistant Examiner—D. C. Reiley, III
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[57] **ABSTRACT**

A method of achieving good thermal interchange between a tube wall and a tube installed fin annulus, providing secondary heat transfer surface, wherein fin corrugations are metallurgically bonded to the tube wall by a method inhibiting the bonding material from flowing to and blocking flow paths between the fin corrugations. A new fin material is used which maintains open flow paths through the fin material even when the material in strip form is rolled to a circular or arcuate configuration.

8 Claims, 7 Drawing Figures

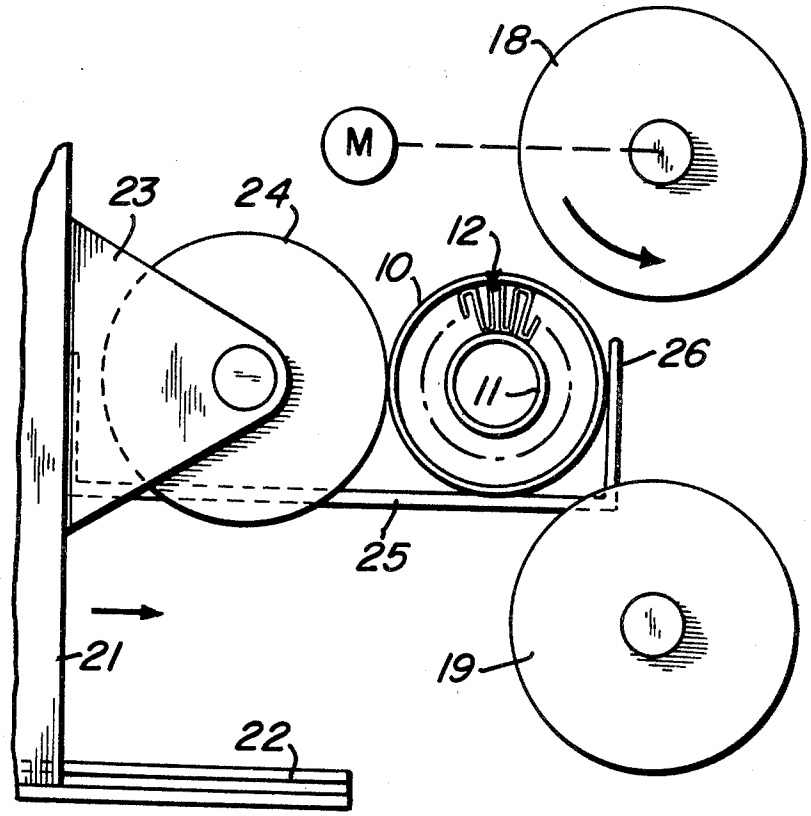


FIG-1

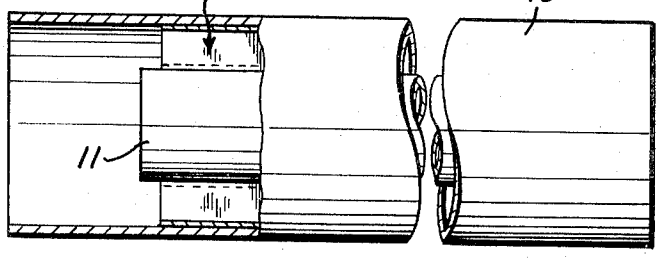


FIG-2

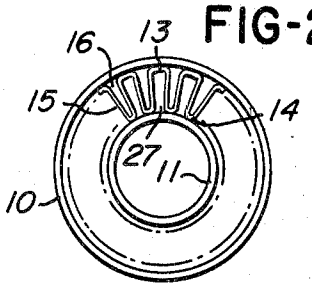


FIG-3

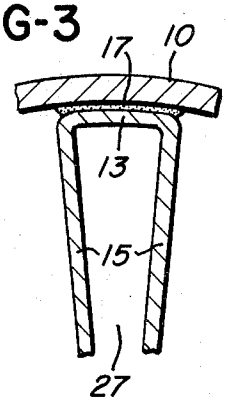


FIG-4

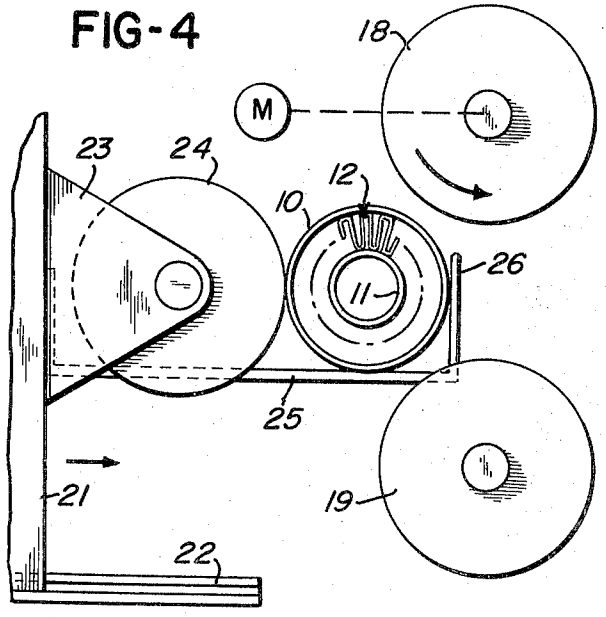


FIG-5

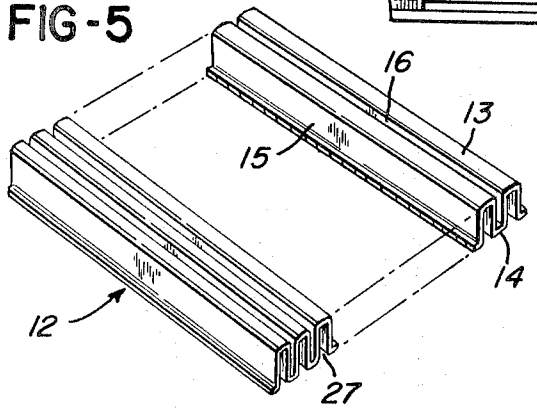
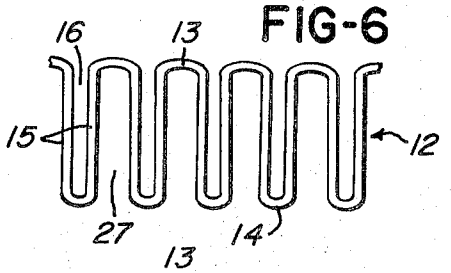


FIG-6



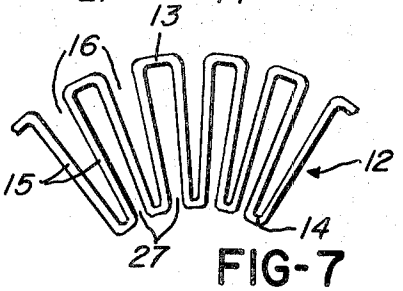


FIG-7

METHOD OF METALLURGICALLY BONDING A INTERNALLY FINNED HEAT EXCHANGE STRUCTURE

BACKGROUND OF THE INVENTION

This invention relates to the heat transfer art and particularly to a method of fabrication of a tube assembly comprising a tube and an interior fin means. The invention further comprehends a fin means uniquely configured to establish and maintain open flow area between fin corrugations when the fin means is rolled and installed in a tube.

Tube assemblies of the kind to which the invention pertains comprise a tube usually arranged in a bundle with other like tubes for a flow of a first fluid over and around the tube exteriors. A second fluid, different in temperature from that of the first and separated therefrom, is passed through the tubes. An exchange of heat occurs through the tube walls. A strip of corrugated metal, termed a fin, is contoured or bent to a circular shape and inserted in the tube where it is in common contact with the tube wall and the internally flowing second fluid. The fin is an extended surface member, supplementing the tube wall in achieving a conduct of heat. It has an efficiency determined in large part by the excellence and continuity of its contact with the tube wall. A high degree of heat transfer efficiency is something to be desired in any heat exchanger design but in compact high performance devices is sought with particular diligence.

In the prior art various methods have been proposed for accomplishing high level heat transfer between the tube wall and fin. Among the more attractive of the proposed methods is metallurgical bonding wherein the crests of the corrugated fin join unitarily to the tube wall through a solder or braze material. According to this concept flowable bonding material would inherently fill any gaps existing between the fin crests and the tube wall, and, ideally, there would be continuous metal to metal contact between the tube and fin. In principle, therefore, metallurgical bonding is an optimal solution to the problem of minimizing contact resistance, that is, resistance to a free flow of thermal energy from the fin to the tube wall, or vice versa.

In practical terms, however, metallurgical bonding has been something less than an unqualified success and is largely unknown in compact high performance heat exchangers. The reasons for this are various. Cost is frequently a factor. For example to apply the solder or braze material it has been suggested that the fin strip or the tube wall, or both, be plated. In most instances the cost of this process offsets the advantages resulting from metallurgical bonding. In another method, it is proposed to feed molten solder into one end of a tube in which a fin annulus has previously been installed. Capillary and other influences are relied upon to position the solder uniformly along the fin crests. Inconsistency obviously inheres in this process, however, with voids occurring in random fashion in the defined metallurgical joints. From engineering and production standpoints it is highly desirable that finished tubes and finished heat exchangers made from such tubes perform to predictable, uniform standards. Such performance is beyond the capabilities of the latter and other known methods practiced or experimented with.

A common denominator in the deficiencies of prior art methods is a problem of plugging of flow passages between fin corrugations caused by molten solder running into the spaces defining these passages and hardening therein. To reduce the flow area of the fin passages is to increase pressure drop, to reduce effective heat transfer area and otherwise adversely to affect the ability of the heat exchanger to carry out its intended function.

The fin strip which forms the fin annulus is made to be more or less dense in terms of the number of fin corrugations per unit of measure. A more dense fin provides greater heat transfer surface but the passages therethrough are more narrow and hence more easily plugged. Moreover the problem of closing or partial closing of fin passages exists apart from plugging by molten solder. A strip rolled to a circular configuration has an inner and an outer periphery of differing diametral dimensions. At and near the inner periphery the fin corrugations are forced closer together, resulting in reduced flow area and a compromised ability to function to design criteria. In the absence of any means to overcome this condition, larger tubes or fins of less dense material must be used resulting in either case in a heat exchanger larger and more expensive than is desirable.

SUMMARY OF THE INVENTION

The present invention has in view a method of making a heat transfer tube or the like in which a flowable metallic bonding material is placed at the interface between the interior tube wall and an inserted fin annulus, the material being normally in a substantially non-flowing condition. The tube assembly comprising the tube and installed fin annulus is heated to a temperature value to reduce the metallic bonding material to a flowable condition. The tube assembly is subsequently cooled below the described temperature value whereby the metallic material solidifies as a bond between the fin annulus and the tube wall. Provision is made substantially to restrict the bonding material to the point of engagement of the fin crests with the tube wall to avoid plugging of spaces between the fin corrugations. For example, during at least a portion of the cooling step of the process the tube assembly may be rotated relatively rapidly about its longitudinal axis. Centrifugal forces are utilized thereby to inhibit flow of the flowable material between the fin corrugations. According to a further aspect of the invention the fin strip material is constructed of flexible strip material crimped to define a plurality of relatively closely spaced continuous fin convolutions or corrugations. Each such corrugation comprises approximately vertical walls interconnecting upper and lower crests which are alternately broad and narrow to form alternately wide and narrow spaces between adjacent fin walls with wide spaces opening to one side of the strip material and narrow spaces opening to the other side. In response to flexing of the strip in a selected direction about an axis parallel to the fin corrugations the relatively wider spaces tend to close and the more narrow spaces tend to open whereby to maintain substantially uniform open flow passages through the fin material.

An object of the invention is to provide an improved method substantially of the class described in which advantages of the metallurgical bonding concept in tube

and fin construction are realized while obviating problems inhering therein in the prior art.

Another object of the invention is to provide fin means of particular utility in avoiding a reduction of flow area in a formed fin, as for example a fin formed to a circular shape and installed in a heat exchange tube.

Other objects and structural details of the invention will appear from the following description, when read in connection with accompanying drawings, wherein:

FIG. 1 is a view in side elevation of a tube assembly produced in accordance with the instant invention, one end of the tube being broken away to show the fin material installed therein;

FIG. 2 is an end view of the tube assembly of FIG. 1;

FIG. 3 is a relatively enlarged fragmentary view showing the soldered joint as defined at the interface of individual fin convolutions and the tube wall;

FIG. 4 is a partly diagrammatic view of apparatus useful in a rotating of the tube assembly;

FIG. 5 is a view in perspective of a fin strip from which the fin annulus is formed;

FIG. 6 is a fragmentary end view of the fin strip as it appears prior to rolling to a circular form; and

FIG. 7 is a view similar to FIG. 6 showing the fin material as it appears in a rolled or formed condition.

Referring to the drawing, a tube assembly as achieved by the method of the invention includes an outer tube **10** made of a metal of good thermal conductivity. The tube **10** is of a uniform diameter, is relatively thin walled and is open at both ends. There may be comprised in the tube assembly an inner tube **11** which may be constructed like the tube **10** but which in any event provides with the outer tube an annular space to be occupied by a rolled strip **12** of thin material. The strip **12** is comprised of a thin gauge, ductile metal of good thermal conductivity. Originally in sheet form it is gathered and crimped to a corrugated formation to define a series of parallel fin convolutions of longitudinal extent. Each convolution or corrugation comprises upper and lower crests in the form of a peak portion **13** and a valley portion **14** connected by approximately vertical or radial wall portions **15.** The fin corrugations are in the illustrated instance straight but may assume a wave-like configuration or any of the other shapes to which material of the present class conventionally is formed.

The method of the invention may involve a preassembly of the parts in which fin strip **12** is rolled to an annular configuration about inner tube **11** with these parts then being inserted as a sub-assembly into outer tube **10.** With the parts so positioned, the strip **12** has an outer surface presented for contact with the inner wall of tube **10** and an inner surface presented for contact with the exterior of inner tube **11.** The parts will preferably have a friction fit in which they are yieldingly held in an assembled relation. If found necessary or desirable to achieve a more uniformly contacting relation of the fin material to the outer tube wall the inner tube **11** may be expanded, as by passing a mandrel therethrough. The method of the invention does not contemplate reliance upon expansion of the inner tube **11** to minimize contact resistance at the outer tube wall, however, but instead provides solid, metallic joints at the peak portions **13** for a direct conduct of heat between the fin material and the tube wall.

In the practice of the metallurgical bonding concept, a solder or braze material is suitably applied at the interface between the peak fin portions **13** and the tube wall. This may variously be done, as for example by pre-plating the interior wall of tube **10** or by pre-plating one or both sides of the strip material **12.** In another possible method the tube **10** is dipped in a molten solder material which coats the interior wall of the tube and when allowed to harden forms a layer of solder material thereon. According to still another possible method a commercially available solder composition in paste form is brushed onto the peak portions **13** of the fin corrugations, the brushing being preferably done in a direction transverse to the long dimension of the fins to avoid depositing solder material in the spaces between the fins. In any event, with solder or braze material present at the interface between the tube wall and the fin strip, the tube assembly is heated and brought to a temperature approximating that at which the solder or braze material is reduced to a flowable condition. When this occurs the bonding material assumes an intimately contacting relation to the tube wall and to the upper fin crests and to such extent as may be required flows along the fin corrugations fully to occupy any voids or gaps which may be present between the peak portions **13** and the tube wall. Upon allowing the tube assembly to cool, the molten material solidifies to form a strong, sound joint between the tube wall and each individual fin crest providing low or substantially no resistance to heat transfer between the tube wall and the fin material.

Installations using a formed tube assembly may include one in which a plurality of formed tubes are disposed in a bundle for flow of a first fluid over and around the tube exteriors. A second fluid, in separated relation to the first is controlled and directed to pass longitudinally through the tubes. In accordance with the concern of the present invention, the flow is in an annular form, inner tube **11** being closed. The flowing fluid is in contact with the inner wall of tube **10** and is also in contact with the material of fin strip **12.** Assuming the fluids to be of different temperature, a transfer of heat takes place through the tube wall. The tube wall serves as primary heat transfer surface with respect to the second fluid in contact therewith. The material of fin strip **12** acts as a secondary surface, conducting heat to or from the tube wall. The soldered or brazed joints at the points of contact of the fin strip with the tube wall insure excellent heat transfer characteristics.

Returning to a consideration of the fabrication method it is desirable to confine the metallic bonding material to a region at or adjacent to the tube wall. In a molten condition the bonding material may tend to move into and occupy a portion of the space between adjacent fin corrugations, which spaces, indicated at **16** in FIG. **2,** act as flow passages for the described second fluid which flows longitudinally through the tubes. If allowed to enter such spaces and subsequently to solidify therein, the bonding material reduces both effective flow and surface area and correspondingly diminishes the heat transfer capabilities of the provided secondary heat transfer surface. This condition may be alleviated by utilizing carefully controlled quantities of bonding material and applying it in a restricted manner, as for example only to the tips of peak portions **13** of the fin strip. In another possible method, heating of the tube assembly to the liquidus temperature of the bonding

material may be effected by blowing hot air through the tubes, with the air temperature being gradually reduced as the critical temperature is reached and surpassed. Air pressure would inherently confine the bonding material to the tube wall and would blow clear the passages between the fin corrugations.

In another contemplated method step, centrifugal force is used to maintain the molten bonding material outwardly at the joints defined by the tube wall and the peak portions **13** of the fin material. In accordance with this inventive concept, the tube assembly is heated in any desired manner to the critical temperature value, immediately following which the tube assembly is placed in a suitable fixture and rotated relatively rapidly about its longitudinal axis. The molten material, including any which may have entered the spaces between the fin corrugations is forced outwardly against the tube wall where it is confined to a formation of the described joints. The tube may be allowed to cool naturally while rotating but in a preferred form of the invention is simultaneously cooled by flowing air longitudinally through the rotating tube. In a cooled, finished tube assembly, as shown in FIGS. **1** to **3**, the flow passages **16** are free of solder or braze material which is present only as a thin band or fillet **17** between each peak portion **13** and a substantially contacted wall portion of the tube **10**.

Rotation of the tube assembly may be by any suitable apparatus. For example, there may be provided, as shown in FIG. **4**, spaced apart rollers or sets of rollers **18** and **19** one of which is positively driven in a rotary sense and the other of which idles or rotates freely. A carriage member **21** slides on a table **22** toward and from the rollers **18** and **19**. Bracket means **23** is mounted to the carriage **21** and supports idler roller means **24** in a horizontal plane passing between the rollers **18** and **19**. Also mounted to the carriage **21** are forwardly projecting finger means **25** terminating in upstanding extremities **26**. The means **25–26** provides a holder upon which a pre-heated tube assembly is placed, in the manner indicated, with upstanding extremities **26** holding the tube **10** substantially to a contacting relation to roller means **24**. As will be evident, upon advance of the carriage **21** to the right, as viewed in FIG. **4**, the tube **10** will achieve further, simultaneous contact with the rollers **18** and **19**. In such position of confinement, and due to the positive rotary drive of one of the rollers **18** and **19**, as for example roller **18**, the tube assembly is put into rotation about its longitudinal axis. There may be provided, in a manner which it is unnecessary here to consider, a compressed air attachment by which air is blown longitudinally through the tube in accompaniment with its rotation.

As heretofore noted, the fin strip **12** is formed from a flat sheet of thin ductile material with the convolutions therein being formed by suitable die elements interacting to effect a gathering or crimping of the sheet material. In accordance with a feature of the invention, the die elements are constructed to achieve differential spacing on opposite sides of the approximately vertical walls which join together upper and lower crests of a formed fin strip. Thus, and as shown in FIGS. **5** and **6**, a formed fin strip comprises the before mentioned spaces or passages **16**, and, intermediately thereof, relatively wider spaces **27**, the former opening through what may be considered an upper side of the fin strip and the latter opening through what may be considered the lower side thereof. In the forming of such differential spaces, the peak portions **13** of the convolutions are made relatively broad and the valley portions **14** made relatively narrow. In the illustrated instance this is accomplished by forming the peak portions to a relatively larger radius than the one to which the valley portions are formed. It will be understood, however, that the peak and valley portions are not necessarily of an arcuate configuration. The crests may be squared off or be made more sharply angular.

In forming the fin strip about the tube **11**, or in otherwise arcuately shaping the strip for installation in a heat transfer duct, the strip is bent about an axis substantially parallel to the long dimensions of the fin corrugations, with the previously defined upper side of the fin strip forming the periphery of larger radius and the described lower side of the strip forming the periphery of smaller radius. Spaces **16** accordingly open through the outer periphery of the formed strip and spaces **27** open through the inner periphery. In the forming process, as seen in FIG. **7**, adjacent valley portions **14** tend to move more closely together while the peak portions **13** tend to separate. Corresponding adjustments in the area of the spaces **16** and **27** result and as a consequence these areas become more nearly alike or in any event tend to maintain their individual identities. In the absence of specially configured fin strip material a rolled fin strip will find the valley portions thereof forced together in a manner materially to restrict flow through the fin annulus with consequent adverse effect upon heat transfer efficiency. In the present instance, and as shown also in FIG. **2**, both sets of flow passages **16** and **27** remain open in the installed position of the fin material, permitting the fin assembly to function in proper accord with its design specifications.

The invention has been disclosed with reference to particular method and structural embodiments. Modifications have been discussed and these and others obvious to a person skilled in the art to which the invention relates are considered to be within the intent and scope of the invention.

What is claimed is:

1. A method of metallurgically bonding a tube contained fin annulus to a tube wall for maximal heat transfer therebetween, including the steps of applying a flowable metallic bonding material so that it is present in a normally non-flowing condition at the interface between the interior wall of a tube and a fin annulus installed in the tube, heating the tube assembly comprising the tube and installed fin annulus to a temperature value to reduce the metallic material to a flowable condition, cooling the tube assembly below said temperature value whereby said metallic material solidifies as a bond between said fin annulus and the tube wall, and confining the bonding material during cooling to a region at the interface between the interior tube wall and said fin annulus to obviate its entrance into and plugging of spaces between fin convolutions, said last named step including a rotating of the tube assembly relatively rapidly about its axis during at least a portion of the cooling step to utilize centrifugal force to inhibit flow of the flowable material between the fin convolutions while maintaining such material at the said interface between said interior tube wall and said fin annulus.

2. A method according to claim **1**, wherein the flowable metallic bonding material is applied as a coating

on the interior tube wall, with the fin annulus being installed in a pre-coated tube for subsequent performance of said heating and cooling steps.

3. A method according to claim 1, wherein the flowable metallic bonding material is applied as a coating to the crests of individual fins of the fin annulus, with the pre-coated fin being installed in a tube for subsequent performance of said heating and cooling steps.

4. A method according to claim 3, wherein said bonding material is applied in paste form.

5. A method according to claim 4, wherein said bonding material is applied in paste form by brushing in a direction transverse to the longitudinal direction of the fins.

6. A method according to claim 1, wherein the tube assembly with the metallic bonding material applied thereto is heated and in a subsequent step is rotated, with cooling being carried on simultaneously with rotation.

7. A method according to claim 1, wherein the fin annulus is comprised of flexible strip material crimped to establish continuous fin convolutions which at peak portions thereof are relatively more broad than at adjacent interconnecting valley portions to define alternately wide and narrow spaces between adjacent fin walls with wide spaces opening to one side of the strip material and narrow spaces opening to the other side.

8. A method according to claim 7, wherein in forming said fin annulus said crimped strip is flexed to a circular configuration with the side having the wide opening spaces facing radially inward.

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