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(54) **HEAT EXCHANGER WITH EXPANDED METAL TURBULIZER**

(75) Inventors: **Bryan Sperandei**, Mississauga (CA); **Allan K. So**, Mississauga (CA); **Thomas Seiler**, Milton (CA)

Correspondence Address:
RIDOUT & MAYBEE LLP
225 KING STREET WEST, 10TH FLOOR
TORONTO, ON M5V 3M2 (CA)

(73) Assignee: **DANA CANADA CORPORATION**, Oakville (CA)

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(57) **ABSTRACT**

A heat exchanger incorporating a turbulizer or heat transfer surface wherein the turbulizer is a corrugated member having parallel spaced-apart ridges and planar portions extending therebetween. The heat transfer surface has a plurality of micro-openings formed over at least a portion of its surface so as to create a uniform porosity over the portions of the turbulizer in which they are provided.

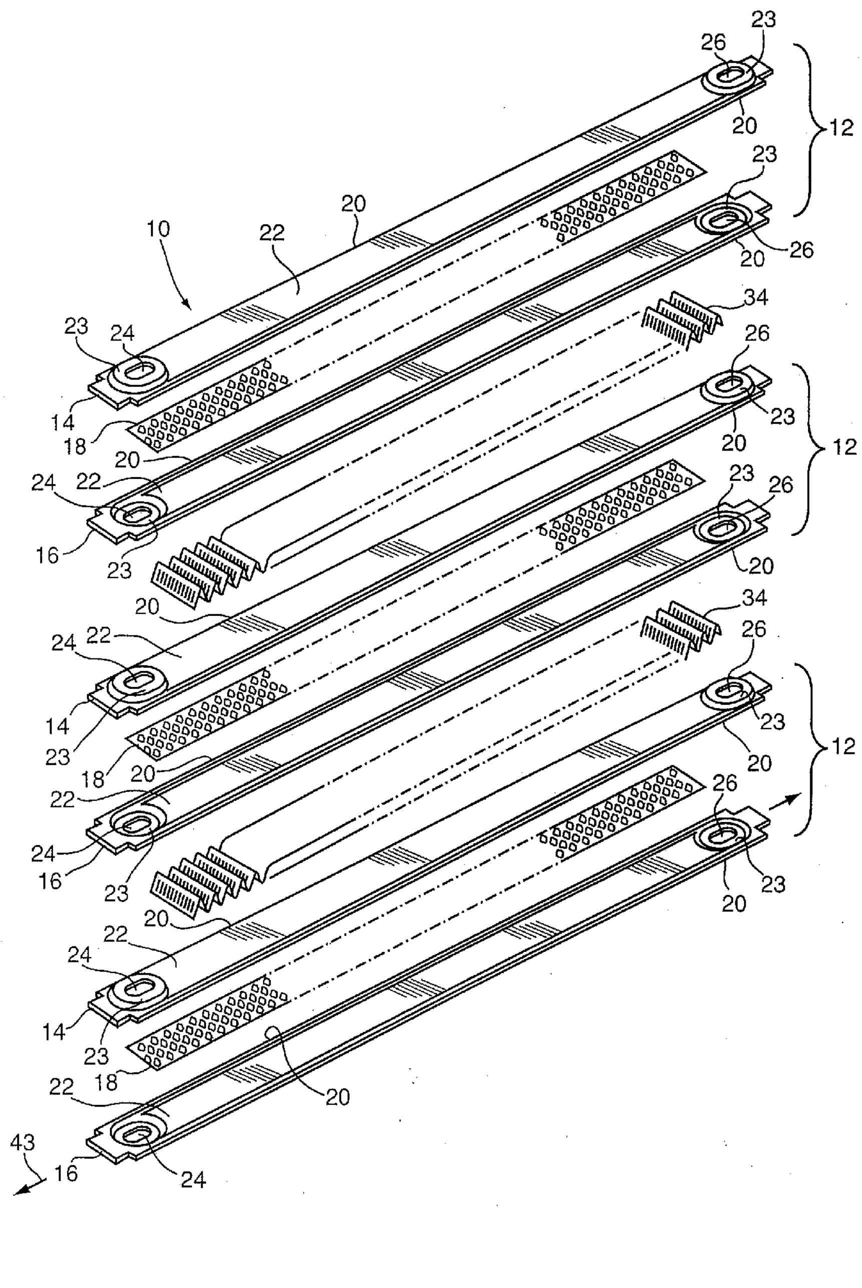


Fig.1

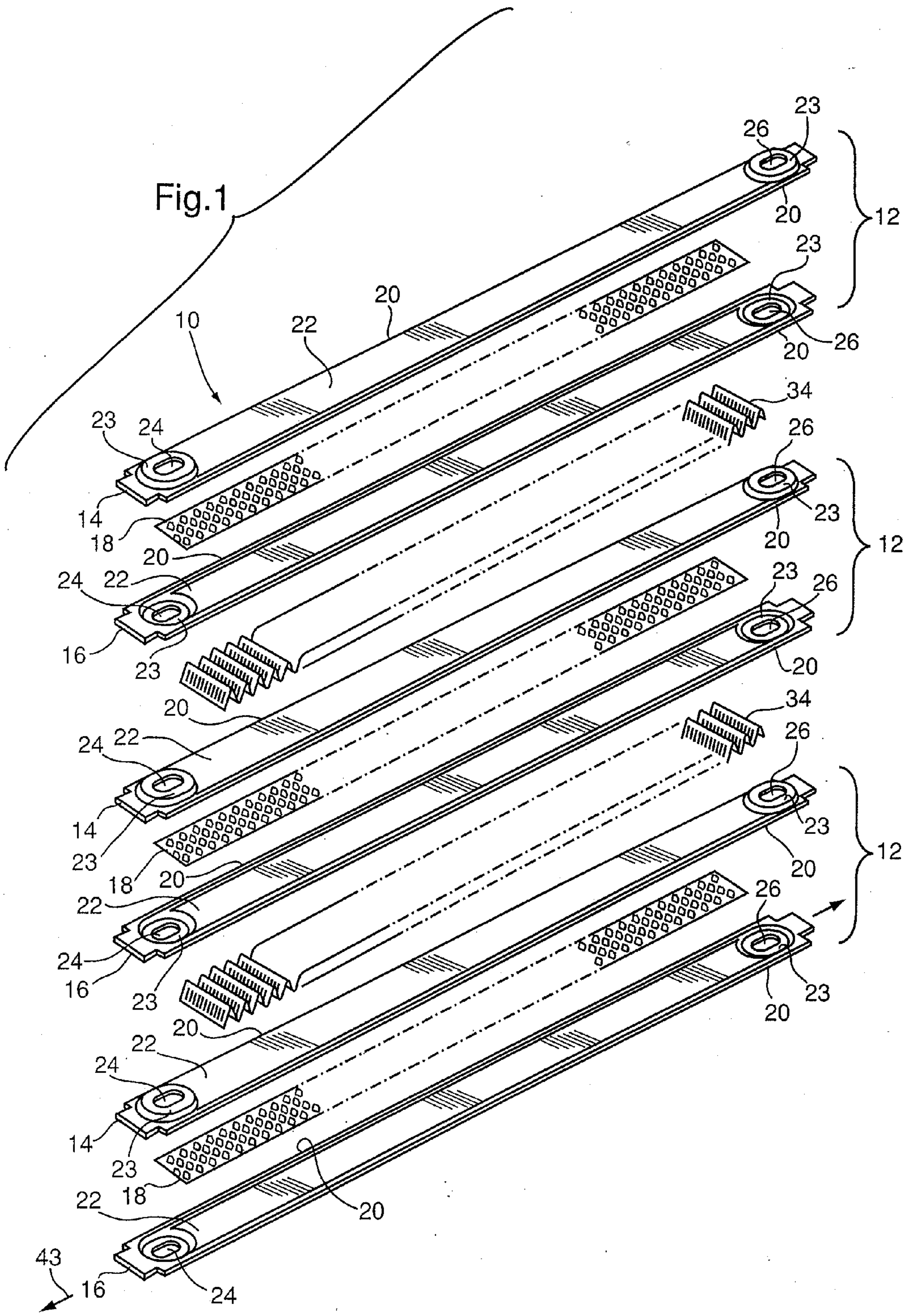
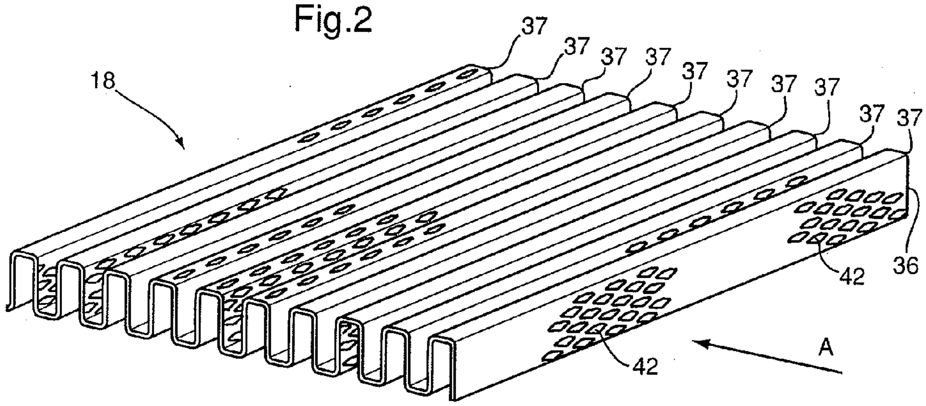


Fig.2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A

Fig3

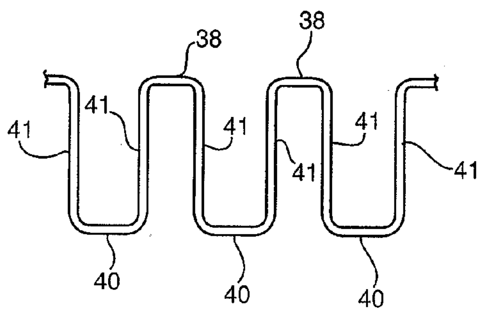
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Fig.4

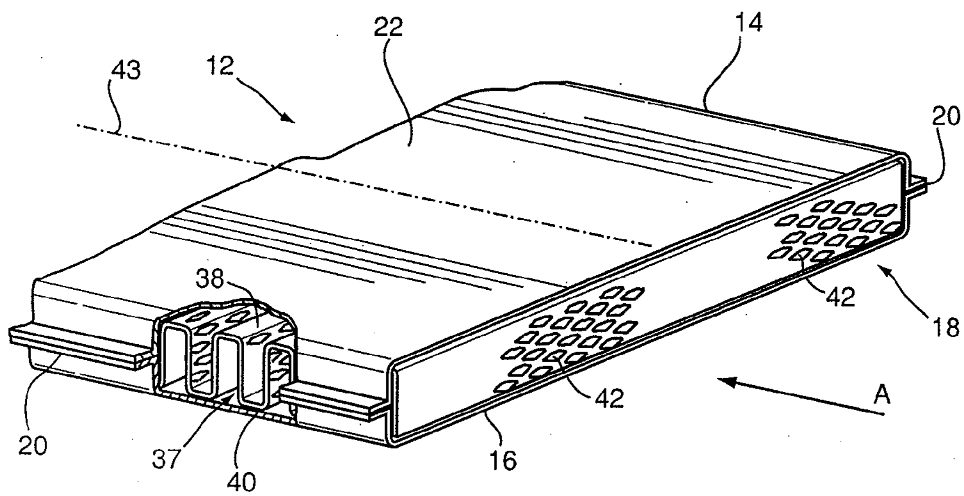


Fig.5

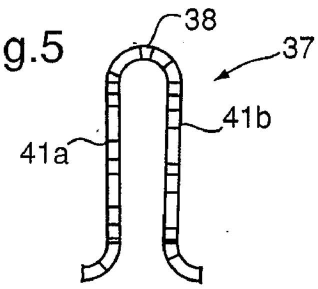


Fig.6

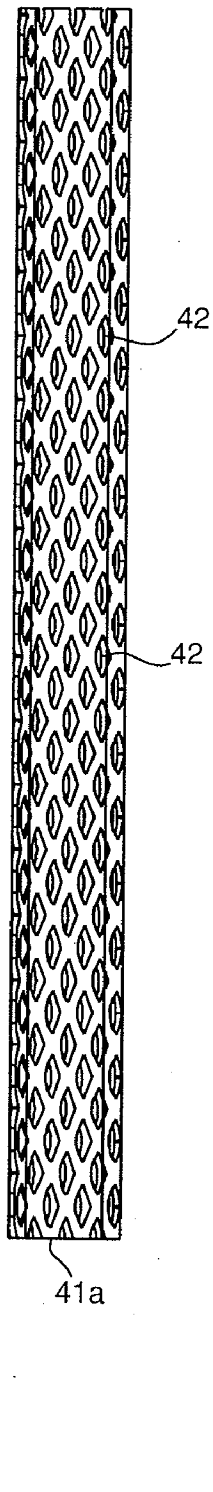


Fig.7

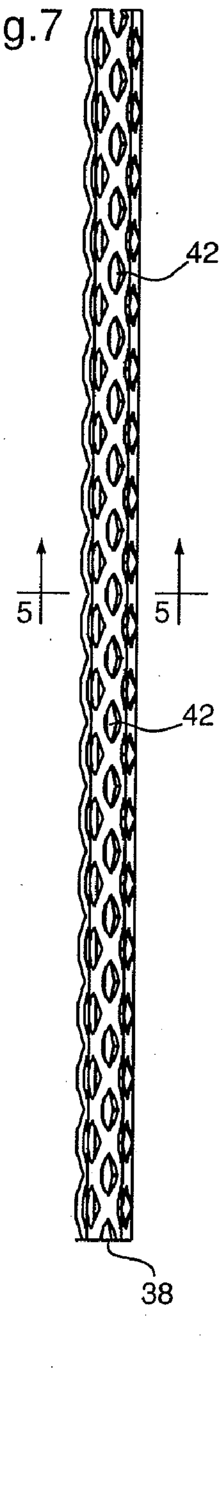


Fig.8

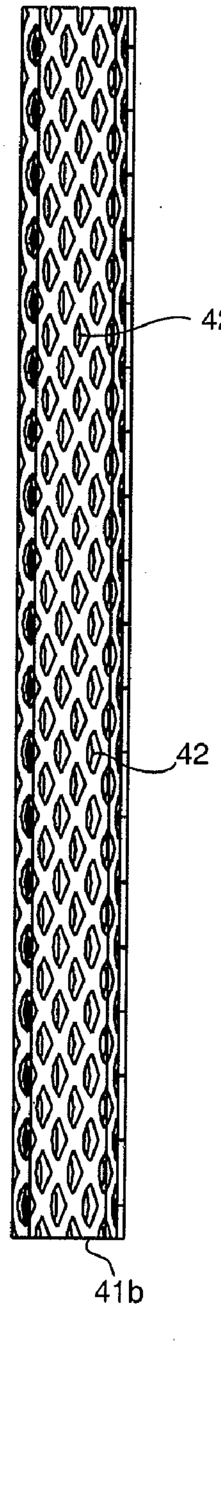


Fig.9

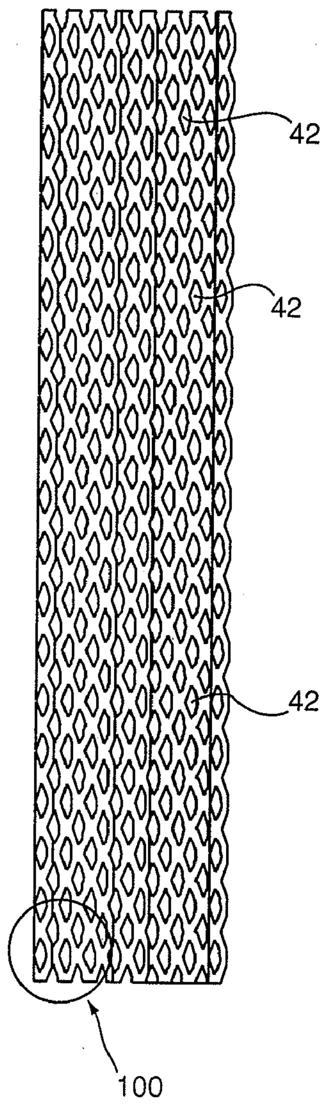


Fig10

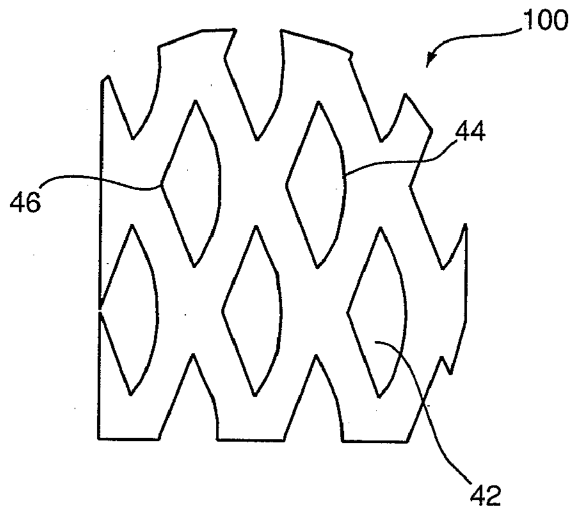


Fig.11

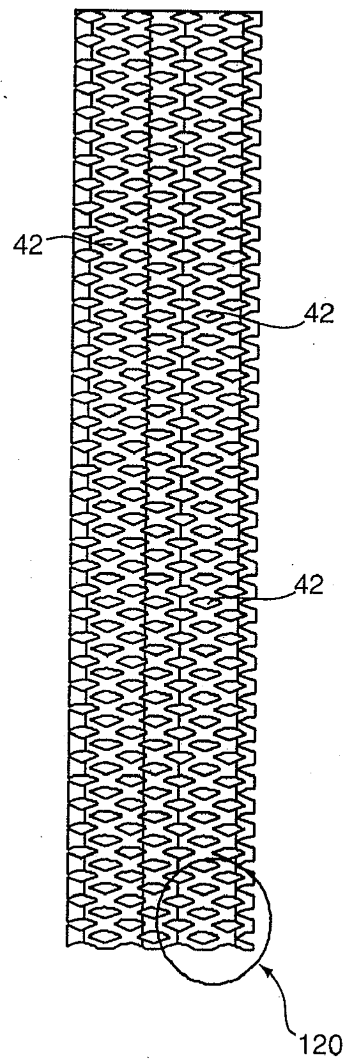


Fig.12

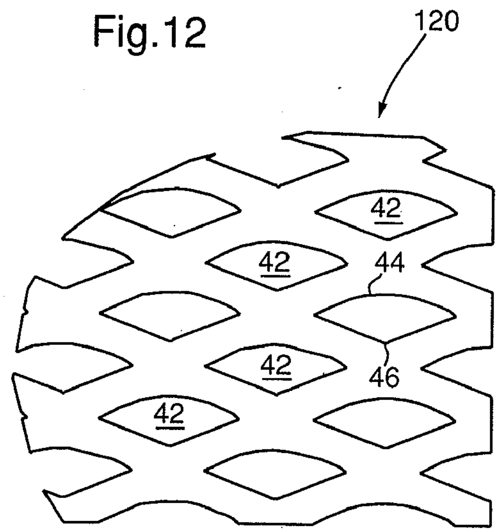


Fig.13

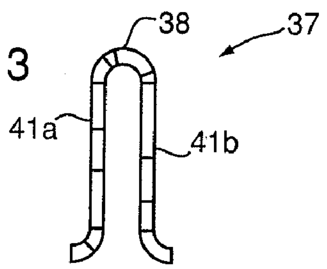


Fig.14

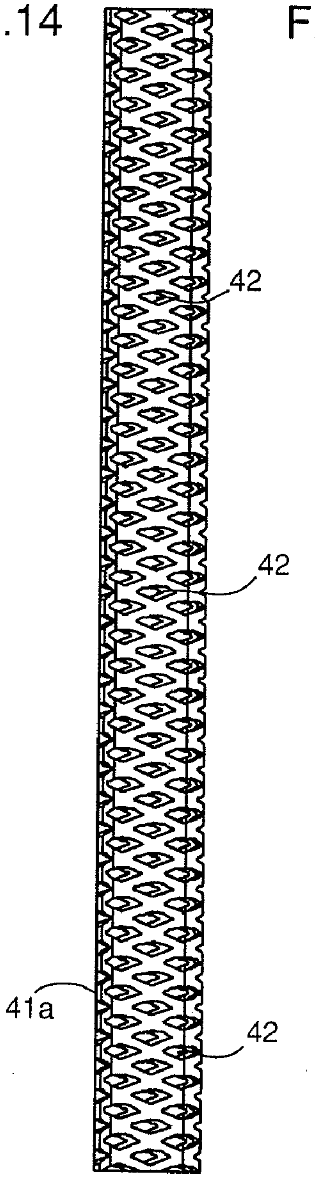


Fig.15

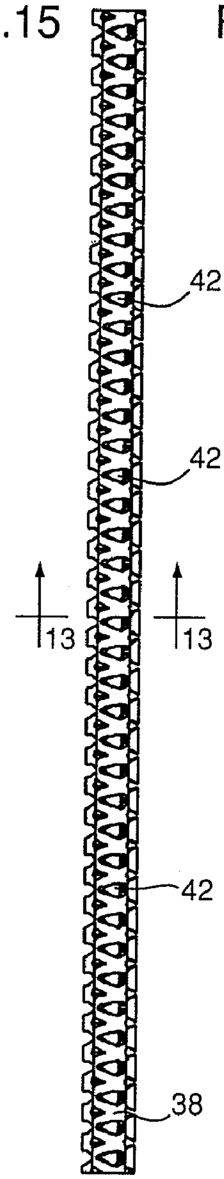


Fig.16

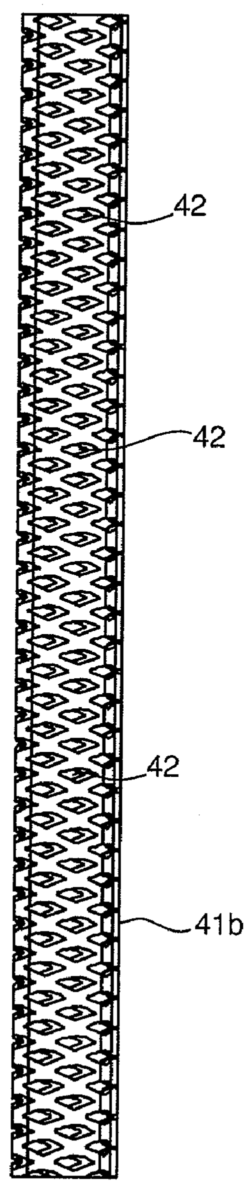
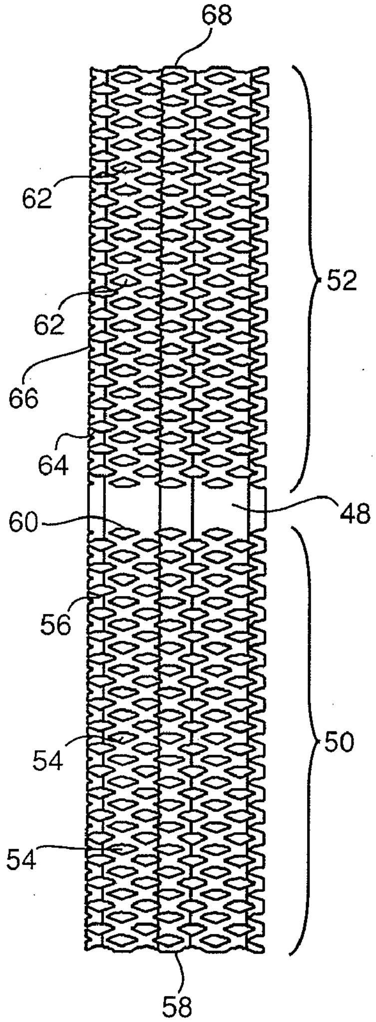


Fig.17



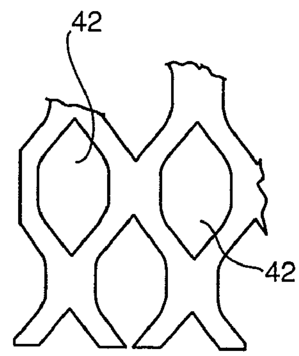
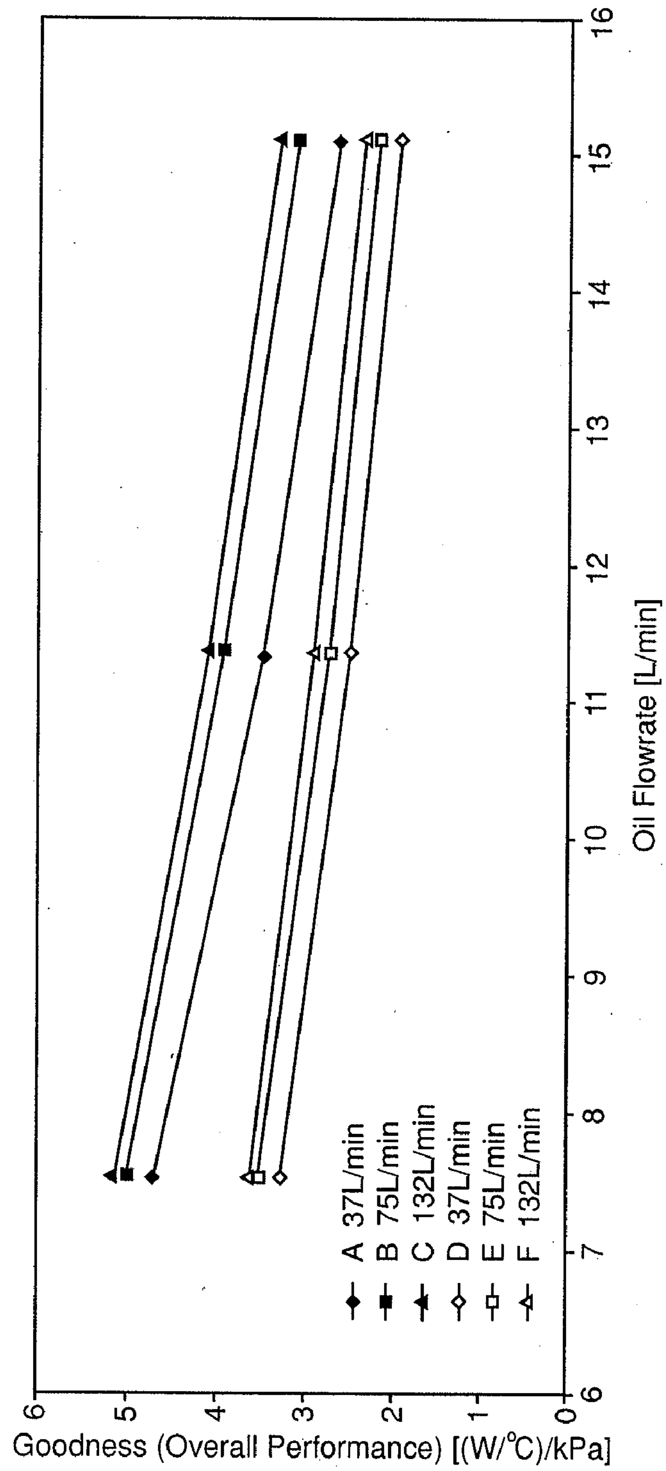


Fig.18

Fig.19


A 37L/min
B 75L/min
C 132L/min
D 37L/min
E 75L/min
F 132L/min
Oil Flowrate [L/min]
Goodness (Overall Performance) [(W/°C)/kPa]
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HEAT EXCHANGER WITH EXPANDED METAL TURBULIZER

FIELD OF THE INVENTION

[0001] The invention relates to heat exchangers, and in particular, to turbulizers used in plate type heat exchangers to increase the heat transfer performance of the heat exchanger.

BACKGROUND OF THE INVENTION

[0002] In heat exchangers, particularly of the type used to cool or heat liquids such as oil, it is common to use flow augmentation devices to increase mixing or flow turbulence or impede the formation of boundary layers and thus improve the heat transfer efficiency of the heat exchangers. In the past, various types of metal fins or turbulizers have been used. One common type of turbulizer is a corrugated fin where the corrugations are formed with a pattern of slits and the material of the corrugations is displaced laterally to produce offset openings. This produces a tortuous flow path through the turbulizer increasing turbulence and breaking up boundary layers.

[0003] U.S. Pat. No. 4,945,981 (Joshi) discloses a fin comprising a plurality of corrugations, the side walls of which are provided with vertical louvers. Louvered fins are commonly used on the air side of an air to liquid heat exchanger; however, in this Joshi patent, the louvered fin is located inside the heat exchanger tubes or channels that normally contain liquids, such as oils. As well, the Joshi patent shows the louvered fin as being positioned within the heat exchanger tubes with the corrugations oriented either parallel or transverse to the flow of the fluid through the channel.

[0004] Japanese application JP-62255792 discloses a heat exchanger having porous thin laminar metallic fins located between adjacent tubes in the heat exchanger. The fins are formed in a waveform shape along a first axis, and in a waveform shape along a second axis where the second axis is perpendicular to the first axis. However, the fins are located external to and in between the tubes of the heat exchanger.

[0005] Some difficulties with expanded metal or louvered type turbulizers is that they produce undesirably high pressure drops or flow losses in the heat exchanger resulting in an irregular or non-uniform flow pattern in the fluid passageways of the heat exchanger. This can produce stagnation in some areas of the heat exchanger, but even if this does not occur, a non-uniform flow profile generally indicates less than ideal heat transfer efficiency through the heat exchanger.

SUMMARY OF THE INVENTION

[0006] According to one aspect of the invention, there is provided a heat exchanger comprising a tubular member having first and second spaced-apart walls defining a flow passage therebetween, the tubular member having respective end portions defining a fluid inlet and a fluid outlet for the flow of a first fluid through the flow passage. A corrugated heat transfer surface is located in the tubular member, the heat transfer surface including parallel spaced apart ridges with planar portions extending therebetween, alternating ridges being in contact with the first and second spaced-apart walls, the corrugated heat transfer surface having a plurality of micro-openings formed therein defining a uniform porosity over the surface thereof. The tubular member having a longitudinal axis, the ridges of the heat transfer surface being oriented perpendicular to the longitudinal axis.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Preferred embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0008] FIG. **1** is an exploded perspective view of a preferred embodiment of a plate type heat exchanger containing a corrugated heat transfer surface according to the present invention;

[0009] FIG. **2** is a perspective view of the heat transfer surface shown in FIG. **1**;

[0010] FIG. **3** is a side elevation view of the heat transfer surface shown in FIG. **2**;

[0011] FIG. **4** is a partial perspective view of a single heat exchanger tubular member containing a heat transfer surface according to the present invention;

[0012] FIG. **5** is a cross-sectional view of a single corrugation of a heat transfer surface according to one embodiment of the invention taken along section line **5-5** shown in FIG. **7**;

[0013] FIG. **6** is a left side view of the corrugation shown in FIG. **5**;

[0014] FIG. **7** is a top view of the corrugation shown in FIG. **5**;

[0015] FIG. **8** is a right side view of the corrugation shown in FIG. **5**;

[0016] FIG. **9** is a top view of a section of material used to form the corrugation shown in FIGS. **5-8**;

[0017] FIG. **10** is an enlarged, detail view of the encircled area **100** of FIG. **9**;

[0018] FIG. **11** is a top view of a section of material used to form a heat transfer surface according to another embodiment of the invention;

[0019] FIG. **12** is an enlarged, detail view of the encircled area **120** of FIG. **11**;

[0020] FIG. **13** is a cross-sectional view of a single corrugation of a heat transfer surface according to another embodiment of the invention taken along section line **13-13** shown in FIG. **15**;

[0021] FIG. **14** is a left side view of a single corrugation shown in FIG. **13**;

[0022] FIG. **15** is a top view of the corrugation of FIG. **13**;

[0023] FIG. **16** is a right side view of the corrugation of FIGS. **13**;

[0024] FIG. **17** is a top view of a section of material used to form a corrugation of a heat transfer surface according to a further embodiment of the invention;

[0025] FIG. **18** is an enlarged detail view of a section of material used to form a heat transfer surface according to another embodiment of the invention; and

[0026] FIG. **19** is a graph of overall performance comparing the efficiency of the heat exchanger of the present invention with a prior art heat exchanger.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] Referring first to FIG. **1**, there is shown a portion of a heat exchanger **10** according to a preferred embodiment of the invention. Heat exchanger **10** is formed of a plurality of tubular members **12**. In the embodiment shown, the tubular members **12** are in the form of plate pairs having an upper plate **14**, a lower plate **16** and a turbulizer **18** located therebetween. Plates **14**, **16** are arranged back-to-back and have joined peripheral edges **20**. Plates **14**, **16** define first and second spaced-apart walls or raised central portions **22** which define a fluid flow passage therebetween in which the turbulizer **18** is located. Raised central portions **22** have respective end portions with raised end bosses **23** which define respective inlet and outlet openings **24**, **26** for the flow of a first heat exchange fluid, such as oil, through the tubular members **12**. The raised end bosses **23** also serve to space-apart the tubular members **12** when they are stacked one on top of the other to form heat exchanger **10**. When the tubular members **12** are stacked together, all of the inlet openings **24** and outlet openings **26** align in fluid communication with each other, thereby forming respective inlet and outlet manifolds. If desired, corrugated fins **34** can be located between the tubular members **12** to act as heat transfer augmentation devices for a second fluid, such as air, flowing transversely through the heat exchanger **10**. The corrugated fins may preferably be provided with vertical slits, or louvers, as shown. While FIG. **1** relates to an oil-to-air heat exchanger **10** having elongate tubular members **12** and corrugated fins, it will be appreciated that turbulizers **18** are not necessarily used in this type of heat exchanger. Rather, it will be appreciated that the turbulizer **18** may be placed within the fluid flow passageways of a variety of different heat exchangers, such as oil-to-water heat exchangers similar to those described by the above-mentioned Joshi patent. Examples of such oil-to-water heat exchangers include transmission oil coolers, engine oil coolers and power steering oil coolers. It will also be appreciated that turbulizers **18** and fins **34** are somewhat schematically shown, and unnecessary details have been omitted, for convenience.

[0028] As shown in FIG. **1**, the tubular members **12** are aligned along a longitudinal axis **43**. Therefore, the direction of fluid flow within the fluid flow passages is also along the longitudinal axis **43**, from the inlet manifold to the outlet manifold.

[0029] Referring next to FIGS. **2** and **3**, there is shown a preferred embodiment of the turbulizer **18** according to the present invention. It will be appreciated that while a particular turbulizer **18** is shown, the turbulizer **18** can be made in any width or length depending on the manufacturing method used and the particular application.

[0030] Turbulizer **18** is a corrugated member **36** having parallel, spaced-apart corrugations **37** defining upper and lower ridges **38**, **40** and planar portions **41** extending between the ridges **38**, **40**. It is preferred, in order to achieve sufficient heat transfer performance, to provide turbulizer **18** with about **15** to about **35** corrugations per inch. Depending upon the degree of contact required between the turbulizer **18** and the inner surfaces of the raised central portions **22** of the plates **14**, **16**, the corrugations or upper and lower ridges **38**, **40** can be shaped so as to have flat top portions, as shown in FIGS. **2** and **3**, or may have more rounded top portions as shown in FIG. **5** described below. The corrugations **37** can also be formed in a triangular configuration, if desired.

[0031] The corrugated member **36** is made from an expanded metal mesh or screen and has a plurality of micro-openings **42** formed therein interconnected by webs of fine metal material. It will be appreciated that the micro-openings **42** are preferably provided over part or all of the planar portions **41**. FIGS. **2** and **3** are intended to illustrate an embodiment in which the micro-openings **42** are provided over the entire surfaces of all the planar portions **41**, but most of the micro-openings **42** are omitted from FIG. **2** for the sake of convenience.

[0032] The micro-openings **42** are preferably arranged in a substantially regular pattern and are preferably of substantially the same size, so as to provide an overall uniform porosity across the portions of the turbulizer surfaces in which they are formed. For example, in the embodiment shown in FIGS. **2** and **3**, the micro-openings **42** are arranged over part or all of the planar portions **41** of turbulizer **18**, so as to provide the planar portions **41** with an overall uniform porosity. Preferably, the overall uniform porosity of the turbulizer surfaces in which micro-openings **42** are provided is within the range of about 50% to about 80%. In other words, in any given surface of the turbulizer **18** in which the micro-openings **42** are provided, such as the planar portions **41** of FIGS. **2** and **3**, the combined open area formed by the micro-openings **42** in that surface accounts for about 50% to about 80% of the total area of that surface. In the embodiment of FIGS. **2** and **3**, therefore, the open area defined by the micro-openings **42** accounts for about 50% to about 80% of the total area of the planar portions **41**. It may be preferred in some embodiments of the invention to limit the overall uniform porosity, defined as above, to the range of about 50% to 70%.

[0033] It will be appreciated that the number of micro-openings **42** per unit area and the overall uniform porosity of the turbulizer **18** are limited in the sense that the overall strength of the turbulizer should not be unduly compromised by the size or number of micro-openings **42** formed in the turbulizer **18**.

[0034] Although FIG. **2** illustrates turbulizer **18** having micro-openings **42** covering the entire surfaces of the planar portions **41** while leaving the upper and lower ridges **38**, **40** imperforate, it will be appreciated that this is not essential. Rather, it will be appreciated that the micro-openings **42** can be distributed over all the surfaces of the turbulizer **18**, including the planar portions **41** and the ridges **38**, **40**, in which all the surfaces of turbulizer **18** preferably have an overall uniform porosity within the ranges discussed above. The provision of imperforate top and bottom surfaces of the ridges **38**, **40** may be preferred as it allows for increased contact between the turbulizer **18** and the raised central portions **22** of the tubular members **12** which can result in a more secure braze or bond between the components of the heat exchanger **10**.

[0035] As mentioned above, the micro-openings **42** are preferably all of substantially the same size and shape in order to assist in providing the surfaces of turbulizer **18** with an overall uniform porosity. It will be appreciated that the micro-openings **42** can be of any shape and size, but are preferably of a shape and size which can be formed by slitting and expanding the thin sheet material without creating cracks in the thin webs of metal material connecting the micro-openings. The shapes and sizes of micro-openings defined herein are specific examples of shapes which the inventors have found to be suitable in order to provide turbulizers according to the invention having acceptable overall uniform porosity, heat transfer characteristics, and pressure drop. It will, however, be appreciated that numerous other shapes and sizes of micro-openings are possible without departing from the scope of the invention. Among other possible shapes of micro-openings, some examples include an expanded "pie shape" with two angular sides and one arcuate side; regular-or irregular polygonal shapes including diamond-shape, tetrahedral, rhombic, hexagonal, triangular etc.; circular or oval shapes; raindrop or teardrop shapes, etc.

[0036] It will be appreciated that the shapes of micro-openings of the embodiments illustrated herein are examples of micro-openings which are conveniently formed by slitting the thin sheet material from which the tubulizer **18** is formed, followed by stretching the sheet material, generally in a direction perpendicular to the direction of the slit, to expand the slit into a micro-opening. Micro-openings produced in this manner typically have two sides which meet at acute angles, i.e. angles of less than 90 degrees.

[0037] The dimensions and the area of the individual micro-openings are dependent on the desired overall uniform porosity of the turbulizer **18**, and are also dependent on the shape. The dimensions and the area of the individual micro-openings are therefore highly variable, and the inventors have found that the area of an individual micro-opening may preferably range from about 0.2 mm^2 to about 3 mm^2.

[0038] FIG. **4** shows a turbulizer **18** positioned inside a tubular member **12** of heat exchanger **10** with the parallel rows of corrugations **37** oriented perpendicular to the longitudinal axis **43** of the tubular member **12**. Therefore, the parallel rows of corrugations **37** are perpendicular to the direction of flow of the first heat exchange fluid within the fluid flow passage defined by tubular member **12**, indicated by arrow A, which is referred to as the "high pressure drop" direction. As the first heat exchange fluid flows through the tubular member **12** it flows through the micro-openings **42** formed in the corrugations **37** thereby causing turbulence in the fluid and decreasing boundary layer growth. The turbulence and reduction in boundary layer increases heat transfer thereby increasing the overall performance of the heat exchanger **10**. As well, the relatively high overall uniform porosity provided by the plurality of micro-openings **42** tends to reduce the pressure drop or fluid losses normally associated with fluid flow in the high pressure drop direction as there is less resistance encountered by the fluid as it flows through the turbulizer **18**. The reduction in pressure drop allows for more uniform flow across the heat exchanger **10**, which also improves the overall performance of the heat exchanger **10**.

[0039] The turbulizer **18** is sized so that the imperforate upper and lower ridges **38**, **40** are in contact with the raised central portions **22** of the upper and lower plates **14**, **16** of tubular members **12**. Typically, the heat exchange components are made of a material suitable for brazing Therefore, the contact between upper and lower ridges **38**, **40** and the inner surfaces of the raised central portions **22** of the plates **14**, **16** allows the upper and lower ridges **38**, **40** to be brazed to the inner surfaces of the raised central portions **22** of the plates **14**, **16**. Applications that require very low pressure drop may require micro-openings larger than 3 mm in area, with ensuing heat transfer reduction.

[0040] Referring now to FIGS. **5-8**, there is shown one corrugation **37** of a turbulizer **18** according to a preferred embodiment. As in FIGS. **1-4**, the micro-openings **42** in FIGS. **5-8** are formed in an expanded pie-shape configuration. In the embodiment of FIGS. **5-8**, the turbulizer **18** is provided with micro-openings **42** over its entire surface, including the entireties of the planar portions **41** and the upper and lower ridges **38**, **40**. In addition, the ridges **38**, **40** of turbulizer **18** of FIGS. **5-8** are rounded, rather than flat.

[0041] In the embodiment of FIGS. **5-8**, all of the expanded pie-shaped openings **42** are of substantially the same size and shape and are arranged in a substantially regular pattern, oriented in the same direction on the sheet of material used to form the turbulizer **18**, with substantially regular spacing between adjacent openings **42**. A portion of the material used to form the turbulizer **18** is shown in FIG. **9** in its flattened state prior to the corrugations **37** being formed therein, with the vertical lines therein representing the lines along which the material will be folded to form the planar portions **41** and ridges **38**, **40**. As all of the openings **42** in the material are oriented in the same direction it can be seen, referring now to FIGS. **6-8**, that the openings **42** on a first planar portion **41*a*** of the corrugation **37** are oriented in the opposite direction as the openings **42** on the other or second planar portion **41*b*** of the corrugation **37**. A detail view of the openings **42** is shown in FIG. **10** wherein the openings have an arcuate side **44** and an angular or V-shaped side **46**. The area of each pie-shaped micro-opening **42** is typically near the lower end of the range of about 0.2 $mm^2$to about 3 mm^2 mentioned above. As for the dimensions of the pie shaped openings, the longest tip-to-tip dimension, measured between the two acute corners, each of which is formed between angular side **46** and arcuate side **44**, is typically about 1.3 mm. The maximum width dimension of the pie-shaped micro-openings **42** is measured transverse to the tip-to-tip dimension, and is typically about 0.5 mm. These same dimensions are applicable to all the pie-shaped micro-openings **42**, as well as pie-shaped micro-openings **54**, **62** described below with reference to FIG. **17**. It will be appreciated that the areas and dimensions of the pie-shaped micro-openings described herein are merely examples of areas and dimensions which have been found acceptable by the inventors, and that the areas and dimensions of acceptable pie-shaped micro-openings may fall outside these parameters.

[0042] FIG. **18** shows a close-up of another shape of micro-opening **42** which has been found acceptable by the inventors. This shape is described herein as diamond-shaped but it could also be generally described as an irregular hexagonal shape. In this type of micro-opening the longest tip-to-tip dimension, measured between the two opposite acute corners, is typically about 2.3 mm and the maximum width dimension, measured perpendicular to the tip-to-tip dimension, is typically about 1.2 mm. This type of micro-opening **42** has an area which is closer to the upper end of the range of about 0.2 $mm^2$to about 3 mm^2, for example the area may be about 2 mm^2.

[0043] Referring now to FIGS. **11** and **12**, there is shown a portion of the material used to form another embodiment of turbulizer **18**; with the vertical lines in FIG. **11** representing the lines along which the material will be folded to form the planar portions **41** and ridges **38**, **40**. This embodiment is similar to the one discussed above in connection with FIGS. **5-10**, however, in this embodiment the expanded pie-shaped micro-openings are rotated 90 degrees with respect to the ones shown in FIGS. **5-10**. Therefore, in this embodiment, the micro-openings **42** on both planar portions **41*a***, **41*b*** of each corrugation **37** are oriented in the same direction as shown in FIGS. **13-16**. The areas and dimensions of the pie-shaped micro-openings of FIGS. **11** and **12** may preferably be the same as those of the embodiment shown in FIGS. **5-8**.

[0044] FIG. **17** shows a portion of the material used to form another embodiment of the turbulizer **18**, according to the present invention, with the vertical lines in FIG. **17** representing the lines along which the material will be folded to form the planar portions **41** and ridges **38**, **40**. This embodiment is similar to those discussed above in connection with FIGS. **5-16**, having expanded pie-shaped micro-openings with an arcuate side **44** and an angular or V-shaped side **46**. As shown, the material is formed with an imperforate strip **48** down the centre thereof. When the material is corrugated to form a turbulizer, the imperforate strip **48** runs perpendicular to the rows of corrugations **37** and serves to add strength to the overall structure of the turbulizer **18**. While only one imperforate strip **48** is shown, it will be understood that multiple, spaced-apart imperforate strips may be provided, as desired. As well, in the subject embodiment, the imperforate strip **48** divides the turbulizer into a first and second region **50**, **52**, one on either side of the imperforate strip **48**. In the first region **50**, it will be noted that the plurality of micro-openings **54** are oriented in a first direction the same as that shown in FIGS. **11-16** with the V-shaped portions **46** directed toward the corresponding end **58** of the corrugation **37** and the arcuate portion **44** directed toward the imperforate strip **48**. In the second region **52**, the plurality of micro-openings **62** are the mirror image of those in the first region **50** with the arcuate portion **44** being directed toward the imperforate strip **48** and the angled portion **46** directed toward the corresponding end **68** of the corrugation **37**.

[0045] While a particular embodiment of a turbulizer **18** including an imperforate strip **48** has been described in connection with FIG. **17**, it will be understood that imperforate strips can be incorporated into any of the turbulizer embodiments described herein.

[0046] To form the turbulizer **18** of any of the embodiments disclosed herein, generally, a thin sheet of aluminum or any other suitable material is formed with a plurality of slits in an appropriate pattern corresponding to the desired porosity for the turbulizer. The material is then stretched thereby expanding the plurality of slits to form the plurality of micro-openings **42** formed in the surface of the turbulizer. The expanded mesh material is then bent or folded transversely along bend lines to form the corrugations **37**. The bend lines are spaced-apart from each other along the length of the material so that when the material is bent ridges **38**, **40** are formed along the bend lines with planar portions **41** of the material extending between the ridges. The steps of stretching/expanding and bending of the material may be performed simultaneously.

[0047] In another embodiment, rather than forming the turbulizer of heat transfer surface **18** from a sheet of material with a plurality of slits that must be expanded, the turbulizer is formed from a sheet of material with a plurality of piercings or punctures spaced over the surface thereof to form the micro-openings **42**. Therefore, the sheet of material only requires bending to form the corrugations **37** that make up the turbulizer **18**;

[0048] As discussed above, turbulizers according to the invention provide improved heat exchange by creating turbulence and reducing boundary layer formation in the fluid, while also reducing the pressure drop typically associated with fluid flowing across a heat exchanger with a turbulizer positioned in the "high pressure drop" direction. FIG. **19** illustrates test results comparing the "goodness" of an oil-to-water heat exchanger having a louvered fin as disclosed by the Joshi patent, positioned in the high pressure drop direction, with an oil-to-water heat exchanger having a turbulizer **18** according to the present invention.

[0049] Goodness is a measure of the ratio of heat exchange to pressure drop and is indicative of overall performance of a heat exchanger. The performance of the Joshi heat exchanger and the heat exchanger according to the invention were measured at three different flow rates: 37 l/min, 75 l/min and 132 l/min. Runs A, B and C relate to tests conducted with a heat exchanger according to the present invention, and Runs D, E and F relate to tests conducted with the Joshi heat exchanger. As shown by the test results, a heat exchanger employing a turbulizer according to the present invention demonstrated consistently better results for all flow rates.

[0050] While the present invention has been described with reference to certain preferred embodiments, it will be understood by persons skilled in the art that the invention is not limited to these precise embodiments and that variations or modifications can be made without departing from the scope of the invention as described herein. For example, while the exemplary embodiment has been described mainly in terms of a plurality of stacked tubular members **12** in the form of plate pairs having raised central portions **22** and joined peripheral edges, it will be understood that the tubular members may instead be formed as a unitary tubular structure. As well, rather than having identical upper and lower plates **14**, **16**, the tubular members may be formed with a female plate having upwardly turned margins and a mating male plate. Furthermore, while the heat exchanger **10** has been described as including a plurality of stacked tubular members, it will be understood that the heat exchanger **10** may comprise as many or as few tubular members as is required for a particular application. For instance, the heat exchanger **10** may comprise only a single tubular member.

We claim:

1. A heat exchanger, comprising:

a tubular member having first and second spaced-apart walls defining a fluid flow passage therebetween, the tubular member having a fluid inlet and a fluid outlet, said fluid inlet and fluid outlet being spaced-apart from each other thereby defining a flow direction from the fluid inlet to the fluid outlet for the flow of a first fluid through said fluid flow passage;

a corrugated heat transfer surface located in said flow passage, the heat transfer surface including parallel spaced-apart ridges with planar portions extending therebetween, alternating ridges being in contact with said first and second spaced apart walls, said corrugated heat transfer surface having a plurality of micro-openings which define porous areas of said corrugated heat transfer surface, said porous areas being located in at least said planar portions, said porous areas having a substantially uniform porosity, and said ridges being oriented perpendicular to the flow direction within said flow passage.

2. A heat exchanger as claimed in claim **1**, wherein the planar portions are inclined with respect to the spaced-apart walls.

3. A heat exchanger as claimed in claim **1**, wherein the planar portions are perpendicular with respect to said spaced-apart walls.

4. A heat exchanger as claimed in claim **1**, wherein the micro-openings are formed in a shape selected from the group consisting of an expanded pie-shape and a diamond shape.

6. A heat exchanger as claimed in claim **1**, wherein the ridges are imperforate surfaces, said micro-openings being formed only in said planar portions of said heat transfer surface.

7. A heat exchanger as claimed in claim **1**, wherein said micro-openings are formed over the entire surface of said heat transfer surface, including said planar portions and said ridges.

8. A heat exchanger as claimed in claim **1**, wherein the porosity of said porous areas of said heat transfer surface is in the range of about 50% to about 80%.

9. A heat exchanger as claimed in claim **1**, wherein said micro-openings have an average area within a range from about 0.2 mm^2 to about 3 mm^2.

10. A heat exchanger as claimed in claim **1**, wherein the ridges are curved surfaces.

11. A heat exchanger as claimed in claim **1**, wherein the ridges are flat surfaces.

12. A heat exchanger as claimed in claim **1**, wherein the corrugated heat transfer surface includes an imperforate strip along the length thereof dividing said heat transfer surface into first and second regions, said imperforate strip being oriented perpendicular to said parallel spaced-apart ridges, with said porous areas being provided on both sides of said imperforate strip.

13. A heat exchanger as claimed in claim **12**, wherein the micro-openings in said first region are oriented in a first direction and the micro-openings in the second region are oriented in a second direction.

14. A heat exchanger as claimed in claim **1**, comprising a plurality of stacked tubular members.

15. A heat exchanger as claimed in claim **14**, wherein said plurality of stacked tubular members are formed by mating plate pairs.

16. A heat exchanger as claimed in claim **15**, wherein each plate pair comprises an upper plate and a lower plate, each plate having a raised central portion and a peripheral edge, the peripheral edges of the upper and lower plates being joined together when said upper and lower plates placed in back-to-back relationship, each plate having respective end portions formed with raised end bosses defining inlet and outlet openings, the respective inlet and outlet openings of each plate pair communicating with each other when said plate pairs are stacked together to form manifolds.

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