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(54) HEAT EXCHANGER TUBES AND COMBO-COOLERS INCLUDING THE SAME

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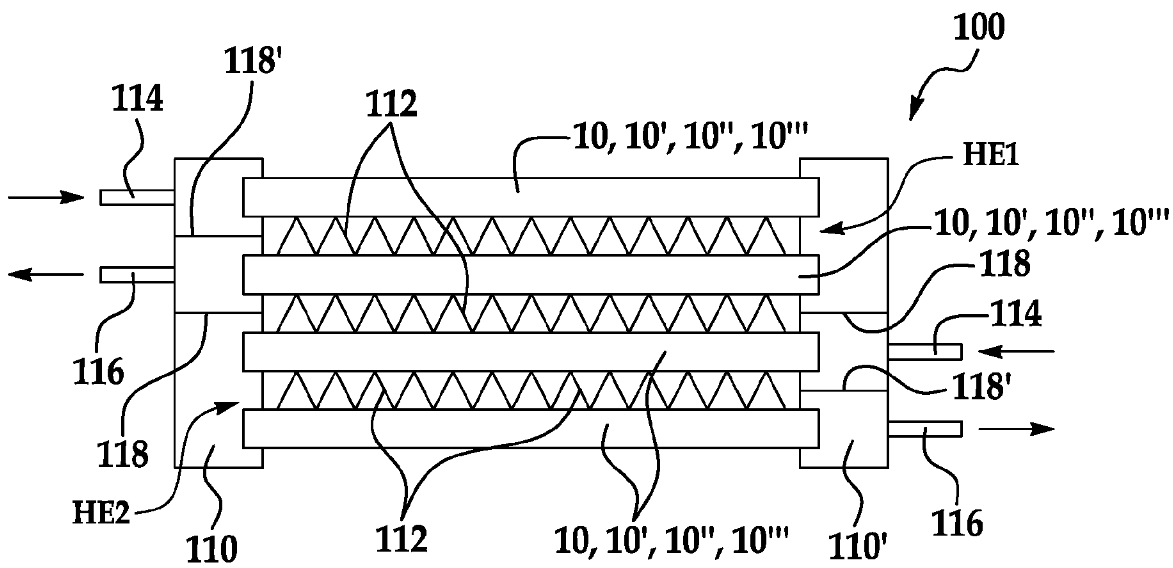
(57) ABSTRACT

A heat exchanger tube includes a tube body and a plurality of flow passages defined therein. The tube body includes two opposed sides, and a wall having a thickness that varies between the two opposed sides.



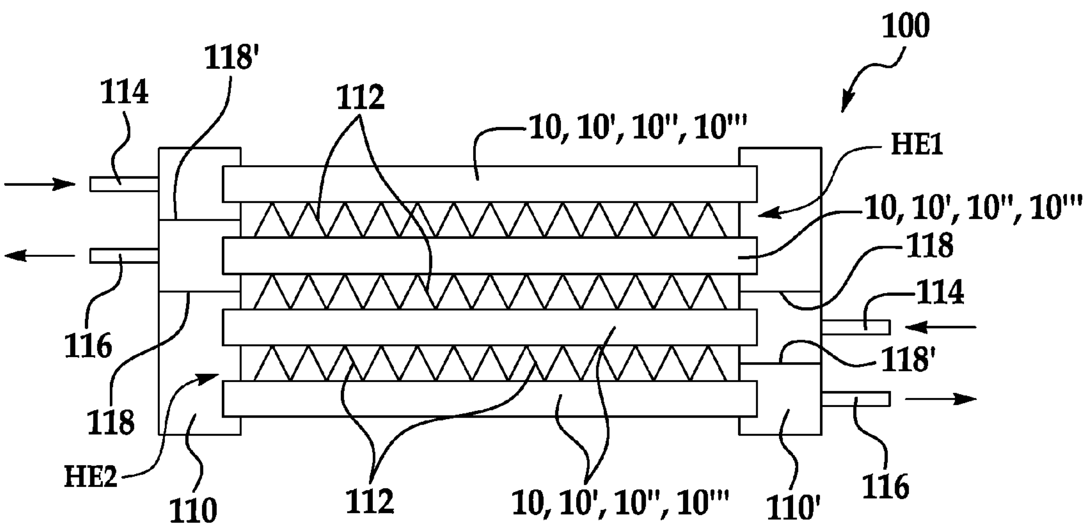

100
118'
114
112
10, 10', 10", 10'"
HE1
10, 10', 10", 10'"
118
114
116
118'
118
116
HE2
110
112
10, 10', 10", 10'"
110'
116

FIG. 1

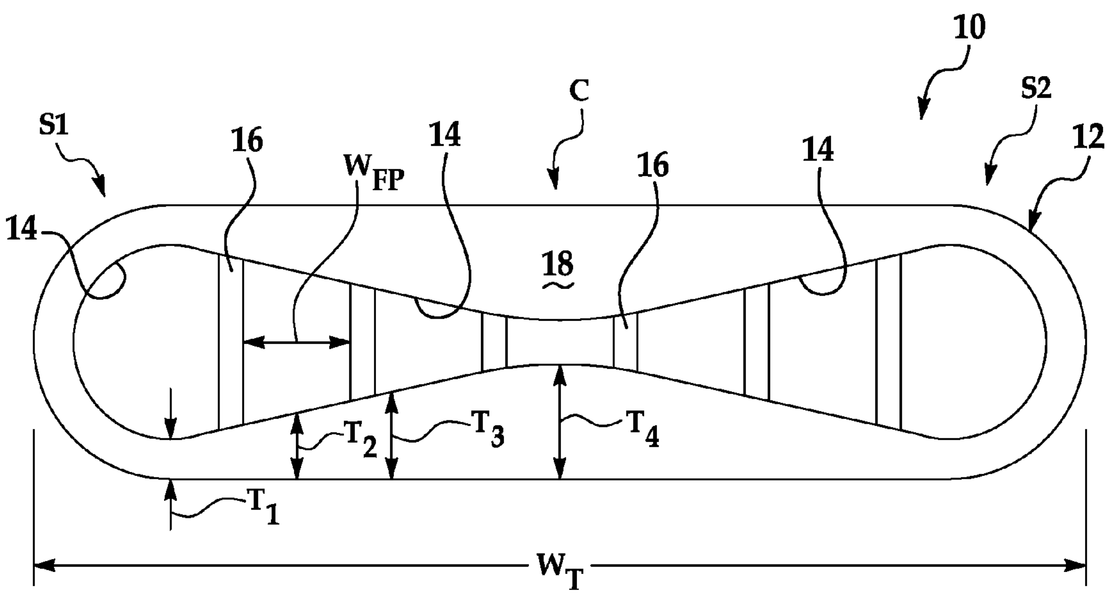

10
C
S2
S1
16
W_{FP}
14
16
14
12
14
18
T_2
T_3
T_4
T_1
W_T

FIG. 2

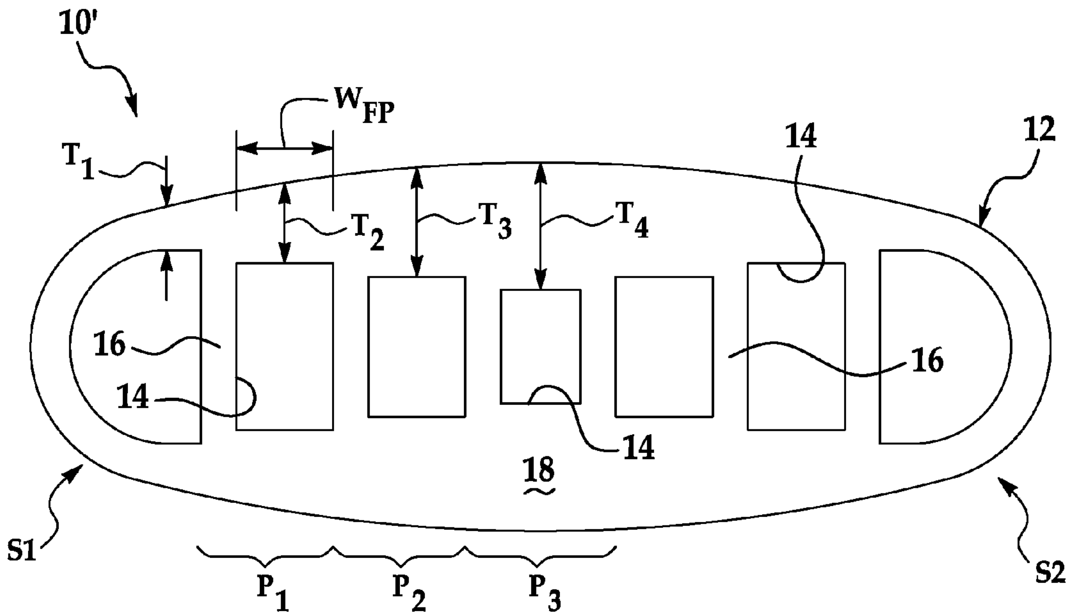


FIG. 3

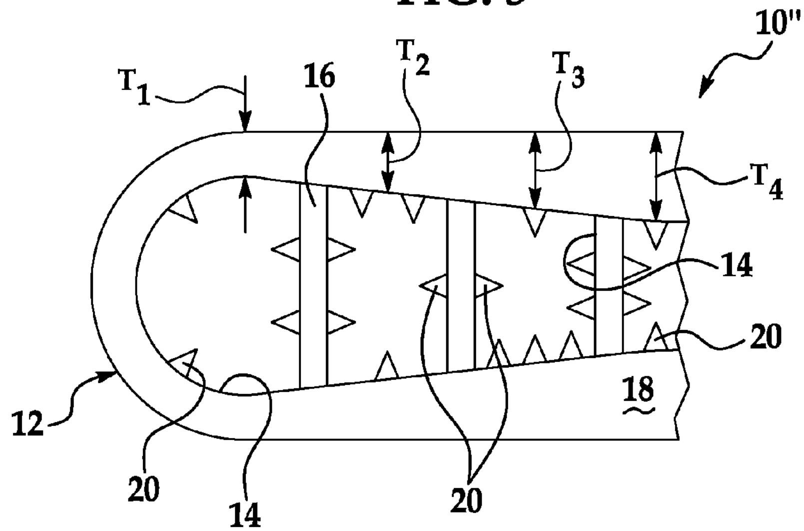


FIG. 4

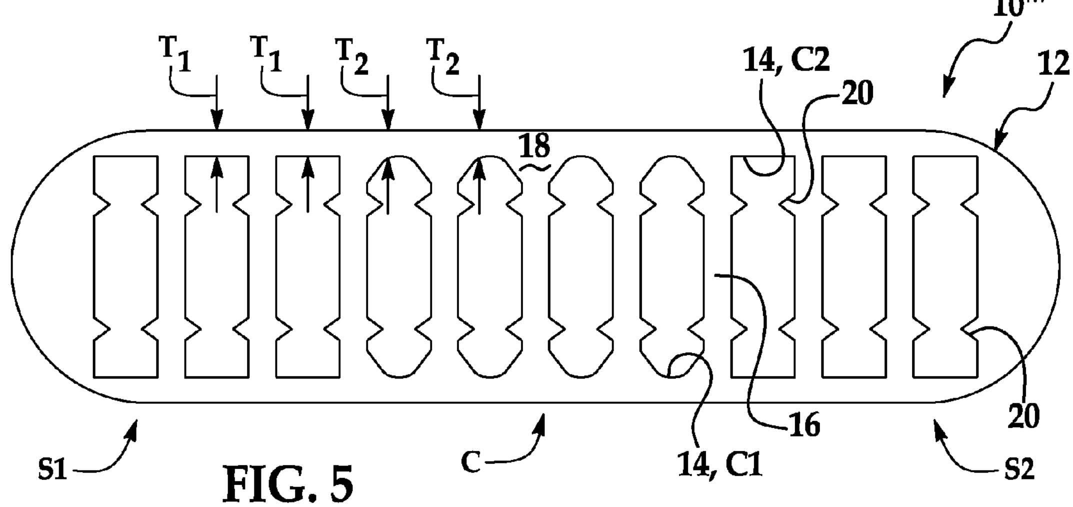


FIG. 5

HEAT EXCHANGER TUBES AND COMBO-COOLERS INCLUDING THE SAME

BACKGROUND

[0001] The present disclosure relates generally to heat exchanger tubes, and to combo-coolers including such heat exchanger tubes.

[0002] Two goals for heat exchanger manufacturing often include forming a product that exhibits efficient transfer of heat, while maintaining a relatively simple manufacturing process. In the automotive industry, in particular, it has also become desirable to combine multiple functions into a single heat exchanger assembly. Combo-coolers are an example of such an assembly and include multiple coolers. In a combo-cooler, the tubes of each cooler are connected to the same pair of manifolds. Oil coolers have been added to automotive combo-coolers. Such oil coolers often have a tube and fin structure, in part because of cost efficiency and ease of assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Features and advantages of embodiments of the present disclosure will become apparent by reference to the following detailed description and drawings, in which like reference numerals correspond to the same or similar, though perhaps not identical, components. For the sake of brevity, reference numerals having a previously described function may or may not be described in connection with subsequent drawings in which they appear.

[0004] FIG. **1** is a schematic view of an embodiment of a heat exchanger assembly;

[0005] FIG. **2** is a schematic cross-sectional view of an embodiment of a heat exchanger tube;

[0006] FIG. **3** is a schematic cross-sectional view of another embodiment of a heat exchanger tube;

[0007] FIG. **4** is a schematic cross-sectional cut-away view of still another embodiment of a heat exchanger tube; and

[0008] FIG. **5** is a schematic cross-sectional view of still another embodiment of a heat exchanger tube.

DETAILED DESCRIPTION

[0009] Embodiments of the heat exchanger tubes disclosed herein advantageously include multiple flow passages, and a varying wall thickness. It is believed that the varying wall thickness decreases thermal stress and improves thermal performance.

[0010] The inclusion of a standard oil cooler into a combo-cooler may increase thermal stress. This may be due, at least in part, to the fact that the tubes of the oil cooler and the tubes of the other coolers (e.g., the condenser) do not expand by the same amount (e.g., length), but are connected to the same manifold. The coefficient of thermal expansion is the same; however, due to the different temperatures, the thermal expansion of the tubes is different. For example, when hot oil flows inside the oil cooler, oil cooler tubes tend to expand, while at the same time, the condenser tube may be cooler, and thus not expand as much. In this case, the manifold may exert compression on the oil cooler tube and tension on condenser tube.

[0011] The present inventors have analyzed failure modes of oil cooler tubes using thermal cycle tests. The tests indicate that the weakest tube is generally the oil cooler tube positioned closest to the condenser. The tests also indicated that the oil cooler tubes were susceptible to the formation of micro-cracks, especially at a center of the tube. The micro-cracks would form at the center, and extend, in general, to the sides of the tubes. As used herein, the term "center of the tube" generally refers to the middle area of the tube when viewing a cross-section of a substantially flat tube, see, for example FIGS. **2** through **5**. Also as used herein, the term "sides of the tube" generally refers to those areas adjacent the opposite ends of the width of the tube when viewing a cross-section of a substantially flat tube.

[0012] Without being bound to any theory, the present inventors believe that by varying the thickness of the tube walls, and by increasing the thickness near the center, the formation of micro-cracks is substantially delayed or eliminated, thereby extending the life and performance of the tube. It is also believed that the varying thickness enhances the durability of the tube for withstanding thermal stress, thereby enabling additional flow passages to be formed in the tubes.

[0013] Referring now to FIG. **1**, an embodiment of a heat exchanger assembly or combo-cooler **100** is depicted. Such an assembly **100** generally includes first and second end tanks or manifolds **110**, **110'**, a plurality of tubes **10**, **10'**, **10''**, **10'''** extending between the end tanks **110**, **110'**, and fins **112** separating each of the plurality of tubes **10**, **10'**, **10''**, **10'''**. Each plurality of tubes **10**, **10'**, **10''**, **10'''** may range from about 100 mm to about 1000 mm in length (i.e., from one end tank **110** to the other **110'**). As shown in FIG. **1**, each of the end tanks **110**, **110'** generally includes an inlet **114**, an outlet **116** and baffles **118**, **118'**.

[0014] One of the inlets **114** and one of the outlets **116** service a first heat exchanger HE**1**, and another of the inlets **114** and another of the outlets **116** service a second heat exchanger HE**2**. Baffles **118** in each of the end tanks **110**, **110'** separate the respective heat exchangers HE**1**, HE**2** from each other. It is to be understood that additional baffles **118'** may be positioned within one or both end tanks **110**, **110'** to direct the flow of fluid within a particular heat exchanger HE**1**, HE**2**.

[0015] It is to be understood that one or more of the tubes **10**, **10'**, **10''**, **10'''** in the combo-cooler **100** includes flow passages (shown in FIGS. **2** through **5**) and a tube body wall having a varying wall thickness. Such tubes **10**,**10'**, **10''**, **10'''** are described in more detail in reference to these other figures.

[0016] While a combo-cooler **100** is shown in FIG. **1**, it is to be understood that the tubes **10**, **10'**, **10''**, **10'''** disclosed herein may be implemented into a single heat exchanger (not shown).

[0017] FIG. **2** depicts a cross-section of one embodiment of such a tube **10**. Generally, the tube **10** includes a tube body **12**, and a plurality of flow passages **14** defined in the tube body **12**. As depicted, each of the flow passages **14** is fluidly separated from each of the other flow passages **14** via a web **16**. It is to be understood that the web(s) **16** may be formed integrally with the tube body **12**, or may be securely attached to the tube body **12**. The tube body **12** and the web(s) **16** may be formed of any suitable material or alloys thereof, including copper, copper alloys, aluminum, or aluminum alloys.

[0018] Examples of processes that may be used to form the tube **10**, flow passages **14**, and webs **16** include, but are not limited to extrusion, roll-forming, or bending and brazing.

[0019] The tube body **12** shown in FIG. **2** is substantially oblong. However, it is to be understood that the tube body **12** may have any desirable configuration. In some instances, an oval shaped tube body **12** may be desirable (see, for example, FIG. **3**).

[0020] The tube body **12** also includes a wall **18** having a thickness (e.g., T_1, T_2, etc.) which varies over a width W_T of the tube body **12**. In one embodiment, the width W_T (also known as core depth) of the tube body **12** ranges from about 8 mm to about 70 mm. Generally, the width W_T of the tube body **12** extends from one side **S1** to an opposed side **S2**. It is to be understood that the wall **18** thickness may vary across the width W_T as is desired, however, as previously described, it may be particularly advantageous to form the thickest portion (see, e.g., thickness T_4) at or near a center C of the tube body **12**.

[0021] The thickness may vary gradually across the entire width W_T (as shown in FIG. **2**), or it may be consistent for a predetermined portion and then vary (as shown and discussed further in reference to FIG. **3**). Generally, the varying thickness ranges from about 0.1 mm to about 0.9 mm. In an embodiment, the wall **18** thickness (see, e.g., T_4) at or near the center C of the tube body **12** ranges from about 0.3 mm to about 0.9 mm, and the wall **18** thickness (see, e.g., T_1) at or near each of the opposed sides **S1**, **S2** ranges from about 0.1 mm to about 0.6 mm.

[0022] In the embodiment shown in FIG. **2**, the wall **18** thickness is substantially symmetrical from the center C to each of the two opposed sides **S1**, **S2**. The thickness increases along the width W_T extending from each of the two opposed sides **S1**, **S2** toward the center C, and as such, it decreases along the width W_T extending from the center C toward each of the two opposed sides **S1**, **S2**. In this embodiment, the wall **18** thickness T_4 is greatest at or near the center C, and the wall thickness T_1 is smallest at or near each of the opposed sides **S1**, **S2**. As shown in FIG. **2**, between the center C and each of the two opposed sides, the thicknesses T_2, T_3 are between the greatest thickness T_4 and the smallest thickness T_1.

[0023] Since the thickness of the wall **18** varies along the entire width W_T of the tube body **12**, the thickness also varies along the width W_{FP} of each individual flow passage **14**. As shown in FIG. **2**, the varying wall **18** thickness affects the cross sectional area of the respective flow passages **14**. Generally, when the thickness increases, the area decreases. As such, in the embodiment shown in FIG. **2**, the cross sectional area of the flow passages **14** closer to the two opposed sides **S1**, **S2** is larger than the cross sectional area of the flow passages **14** closer to the center C.

[0024] It is to be understood that in other instances (not shown in the Figures), the thickness along the width W_T is not symmetrical, rather it increases extending from each of the two opposed sides **S1**, **S2** toward some other predetermined point (i.e., other than the center C). In such embodiments, the thickness is asymmetrical.

[0025] Referring now to FIG. **3**, a cross-section of another embodiment of the tube **10'** is depicted. In this embodiment, the wall **18** has at least three portions **P1**, **P2**, **P3**. Along a particular portion **P1**, **P2**, **P3**, the thickness of the wall **18** remains substantially consistent, but from one portion **P1**, **P2**, **P3** to another portion **P1**, **P2**, **P3**, the thickness of the wall **18** changes. As such, the thickness of the wall **18** is consistent at some point(s) along the width W_T of the tube body **12**, and varies at other point(s) along the width W_T of the tube body **12**.

[0026] In the embodiment shown in FIG. **3**, the portions **P1**, **P2**, **P3** substantially align with a width W_{FP} of a respective flow passage **14**. It is to be understood that the portions **P1**, **P2**, **P3** may extend beyond the width W_{FP} of the flow passages **14** (as shown in FIG. **3**), depending at least in part, on where along the width W_T of the tube body **12** it is desirable to vary the thickness. As such, in some embodiments, a consistent wall **18** thickness is adjacent at least one particular flow passage **14**. For example, the thickness T_2 is consistent along portion **P1**, which includes the entire width W_{FP} of the flow passage **14** directly adjacent thereto, and the thickness T_3 is consistent along portion **P2**, which includes the entire width W_{FP} of the flow passage **14** directly adjacent thereto. As depicted, the thickness T_2 is different from the thickness T_3. In other instances, it may be desirable to extend a particular thickness (e.g., T_1, T_2, T_3, T_4) along two or more adjacent flow passages **14**.

[0027] FIG. **3** again depicts that the thickness is substantially symmetrical from the center C towards the two opposed sides **S1**, **S2**. As previously described, it is to be understood that the thickness may vary as desired. Also as previously described, it may be particularly suitable to have the thickest wall **18** at or near the center C of the tube body **12** (even when the thickness is not symmetrical).

[0028] Still further, it is to be understood that the portions **P1**, **P2**, **P3** do not have to be aligned with the respective flow passages **14**, and may be configured as is desirable for a particular end use. For example, the thickness T_4 at the center C may be substantially consistent along the width W_{FP} of the flow passage **14** directly adjacent thereto, while the rest of the wall **18** thickness T_3, T_2, T_1 may gradually vary along the remainder of the width W_T of the tube body **12** (e.g., as shown in FIG. **2**).

[0029] FIG. **4** depicts cross-sectional view of still another embodiment of the tube **10"**. In this embodiment, micro-fins **20** are established on the wall **18**, the web(s) **16** and/or combinations thereof. It is to be understood that the micro-fins **20** are formed such that they protrude into an interior of the flow passage(s) **14**. The micro-fins **20** may be formed integrally with the wall **18** and/or web **16**. It is believed that the micro-fins **20** further enhance the thermal performance of the tube **10"**.

[0030] Referring now to FIG. **5**, another cross-section of another embodiment of the tube **10'"** is depicted. In this embodiment, the configuration of the flow passages **14** alters the thickness of the wall **18**. As shown, at least some of the flow passages **14** have a first configuration **C1** (e.g., oval), and at least some other of the flow passages **14** have a second configuration **C2** (e.g., rectangular) that is different than the first configuration **C1**. Generally, any suitable configurations **C1**, **C2** may be used, as long as at least a portion of the thickness T_1 of the wall **18** adjacent the flow passages **14** having first configuration **C1** is different from at least a portion of the thickness T_2 of the wall **18** adjacent the flow passages **14** having the second configuration **C2**. In this embodiment, the flow passages **14** at or near the center C of the tube body **12** have a configuration **C2** which results in at least a portion of the wall thickness T_2 adjacent thereto being greater. In this embodiment, the average wall thickness T_2 is larger than the average wall thickness T_1, at least in part, because of the special (e.g., rounded) shape of the ends of the flow passages **14** having configuration **C1** compared with the flat ends of the flow passages of the configuration **C2**.

[0031] In FIG. **5**, micro-fins **20** are also shown formed integrally with the webs **16** such that they protrude into an interior of the flow passage(s) **14**. As previously stated, it is believed that the micro-fins **20** further enhance the thermal performance of the tube **10'"**.

[0032] To further illustrate the embodiment(s) of the present disclosure, an example is given herein. It is to be understood that this example is provided for illustrative purposes and is not to be construed as limiting the scope of the disclosed embodiment(s).

EXAMPLE

[0033] A combo-cooler with 22 mm×4 mm tubes, each including **13** flow passages was formed. This combo-cooler has a varying thickness between the sides, and the thickness averaged 0.45 mm. The combo-cooler was exposed to thermal cycles until failure. A comparative combo-cooler with 22 mm×4 mm tubes, each including **12** flow passages and a uniform wall thickness (0.45 mm along the tube width) was also tested. The results are shown in Table 1 below.

TABLE 1

	Combo-Cooler Having Variable Thickness and 13 Flow Passages	Comparative Combo-Cooler Having Uniform Thickness and 12 Flow Passages
Number of Thermal Cycles until Failure	10630	10390

[0034] The results clearly indicate that the varying wall thickness substantially enhances the life and efficiency of the tubes. Additional flow passages generally decrease tube resistance to thermal cycles. As such, it was expected that the combo-cooler including more flow passages would have failed prior to the combo-cooler having less flow passages. The results indicate that varying the wall thickness increases the durability of the tubes, thereby allowing additional flow passages to be formed therein and improving the thermal cycle performance.

[0035] Embodiments of the heat exchanger tubes **10**, **10'**, **10"** disclosed herein advantageously include a varying wall **18** thickness. It is believed that the varying wall **18** thickness, delays, decreases or eliminates the formation of micro-cracks at thicker areas, and reduces the amount of material used at thinner areas. It is also believed that the varying thickness also advantageously enhances the durability of the tube **10**, **10'**, **10"** for withstanding thermal stress, and enhances the overall efficiency of the combo-cooler **100**.

[0036] While several embodiments have been described in detail, it will be apparent to those skilled in the art that the disclosed embodiments may be modified. Therefore, the foregoing description is to be considered exemplary rather than limiting.

What is claimed is:

1. A heat exchanger tube, comprising:

a tube body, including:

two opposed sides; and

a wall having a thickness that varies between the two opposed sides; and

a plurality of flow passages defined in the tube body.

2. The heat exchanger tube as defined in claim **1** wherein the tube body has a width measured from one of the two opposed sides to an other of the two opposed sides, and wherein the wall thickness increases along the width extending from each of the two opposed sides toward a predetermined distance from each of the two opposed sides.

3. The heat exchanger tube as defined in claim **2** wherein an area of the flow passages decreases as the wall thickness increases.

4. The heat exchanger tube as defined in claim **1** wherein the wall thickness is greatest at or near a center of the tube body between the two opposed sides.

5. The heat exchanger tube as defined in claim **4** wherein the wall thickness decreases extending from the center to each of the two opposed sides.

6. The heat exchanger tube as defined in claim **5** wherein the wall thickness at the center of tube body ranges from about 0.3 mm to about 0.9 mm, and wherein the wall thickness at each of the two opposed sides ranges from about 0.1 mm to about 0.6 mm.

7. The heat exchanger tube as defined in claim **5** wherein the wall thickness is symmetric from the center to each of the two opposed sides.

8. The heat exchanger tube as defined in claim **1** wherein the wall thickness is consistent adjacent respective flow passages, and varies from at least one of the plurality of flow passages to another of the plurality of flow passages.

9. The heat exchanger tube as defined in claim **1**, further comprising a web formed of the tube body that fluidly separates each of the plurality of flow passages.

10. The heat exchanger tube as defined in claim **9**, further comprising micro-fins established on the wall, the web or combinations thereof, such that the micro-fins extend into at least one of the plurality of flow passages.

11. The heat exchanger tube as defined in claim **1** wherein the tube body has a substantially oval or oblong shape.

12. The heat exchanger tube as defined in claim **1** wherein the varying wall thickness ranges from about 0.1 mm to about 0.9 mm.

13. The heat exchanger tube as defined in claim **1** wherein the wall has at least two portions, wherein a first of the at least two portions has a first uniform thickness, and wherein a second of the at least two portions has a second uniform thickness that is different from the first uniform thickness.

14. The heat exchanger tube as defined in claim **1** wherein at least some of the plurality of flow passages have a first configuration, wherein at least some other of the plurality of flow passages have a second configuration different than the first configuration, and wherein the wall thickness adjacent the first configuration is different than the wall thickness adjacent the second configuration.

15. A combo-cooler, comprising:

at least two end tanks; and

a plurality of heat exchangers established between the at least two end tanks, at least one of the plurality of heat exchangers having a tube, including:

a tube body with two opposed sides and a wall having a varying thickness between the two opposed sides; and

a plurality of flow passages defined in the tube body.

16. The combo-cooler as defined in claim **15** wherein each of the plurality of heat exchangers has a tube width ranging from about 8 mm to about 70 mm.

17. The combo-cooler as defined in claim **15** wherein the wall thickness is greatest at or near a center of the tube body, and wherein the wall thickness decreases extending from the center to each of the two opposed sides.

18. The combo-cooler as defined in claim **17** wherein the wall thickness is symmetric from the center to each of the two opposed sides.

19. The combo-cooler as defined in claim **15**, further comprising:

a web formed of the tube body that fluidly separates each of the plurality of flow passages; and

a plurality of micro-fins established on the wall, the web or combinations thereof, such that the plurality of micro-fins extends into at least one of the plurality of flow passages.

20. The combo-cooler as defined in claim **15** wherein the wall has at least two portions, wherein a first of the at least two portions has a first uniform thickness, and wherein a second of the at least two portions has a second uniform thickness that is different from the first uniform thickness.

21. The combo-cooler as defined in claim **15** wherein at least some of the plurality of flow passages have a first configuration, wherein at least some other of the plurality of flow passages have a second configuration different than the first configuration, and wherein the wall thickness adjacent the first configuration is different than the wall thickness adjacent the second configuration.

22. A method for increasing thermal stress resistance of a heat exchanger tube, the method comprising:

varying a thickness of a wall between two opposed sides of a tube body; and

forming a plurality of flow passages in the tube body.

23. The method as defined in claim **22** wherein varying the wall thickness includes increasing the thickness along a width of the tube body extending from each of the two opposed sides toward a predetermined distance from each of the two opposed sides.

24. The method as defined in claim **22** wherein varying the wall thickness includes symmetrically decreasing the thickness from a center of the tube body toward each of the two opposed sides.

25. The method as defined in claim **22**, further comprising:

forming a web of the tube body that fluidly separates each of the plurality of flow passages; and

forming a plurality of micro-fins on the wall, the web or combinations thereof, such that the plurality of micro-fins extends into at least one of the plurality of flow passages.

* * * * *