A corrugated fin or turbulator for a heat exchanger comprises a series of corrugations with parallel side walls. The side walls are provided with a series of parallel slits between which one-sided or two-sided louvers are defined. Each of the louvers has first and second edges extending along an adjacent pair of slits, and at least one bend located between the edges, thereby causing at least one of the edges of the louver to project outwardly of the plane of the side wall, and providing the side wall with improved crush resistance. The corrugations may preferably be rectangular or trapezoidal in form, having generally flat top and bottom surfaces defined by two closely-spaced bends. The top and bottom surfaces may preferably be provided with protrusions, at least some of which extend close to the bends. This assists in creating localized areas of weakness along which the bends can be formed cleanly.
HEAT EXCHANGERS WITH CORRUGATED HEAT EXCHANGE ELEMENTS OF IMPROVED STRENGTH

FIELD OF THE INVENTION

[0001] The invention relates to heat exchangers and corrugated heat exchange elements for use therein, and particularly to corrugated heat exchange fins and turbulators of improved strength and manufacturability, and to heat exchangers incorporating such fins and turbulators.

BACKGROUND OF THE INVENTION

[0002] Heat exchangers are commonly provided with heat exchange elements such as corrugated fins and/or turbulators in order to enhance heat transfer between two or more fluids. Corrugated fins and turbulators are structurally similar, and typically comprise a thin metal sheet in which parallel bends define a series of corrugations of a generally rectangular or triangular form. A turbulator is generally inserted inside a fluid flow passage defined by the interior of a tube or a plate pair, whereas a fin is generally mounted on an exterior surface of a tube or plate pair. The fluids which come into contact with these heat exchange elements may be on the hot or cold heat transfer side and may consist of gaseous, liquid or two-phase fluids.

[0003] Corrugated heat exchange elements can take the form of corrugated turbulators such as those described in U.S. Pat. No. 4,945,981 (Joshi) issued on Aug. 7, 1990. Joshi describes an automotive oil cooler comprising a pair of plates defining an oil passage with a turbulator inserted therein. The Joshi turbulator comprises a metal foil having a plurality of parallel V-shaped corrugations and is oriented in the oil passage with the longitudinal direction of the corrugations extending either parallel or transverse to the direction of oil flow. The top and bottom surfaces of the corrugations are in heat exchange contact with the plates of the oil cooler and are preferably brazed to the plates. The side surface of each corrugation is provided with a series of louvers which create turbulence in the oil and enhance heat transfer. Where the corrugations are transverse to the flow direction, the oil must flow through the louver openings in order to pass from the inlet to the outlet.

[0004] One disadvantage of the Joshi turbulator is that the triangular or V-shaped corrugations make contact with the plates only along the relatively narrow top and bottom surfaces of the turbulator, thereby limiting heat transfer. Furthermore, the sloping side walls of the Joshi turbulator result in the formation of relatively large spaces between adjacent side walls. Where the corrugations are aligned parallel to the direction of fluid flow, there is significant duct flow between the side walls, which results in poor heat transfer.

[0005] Heat exchange elements having rectangular corrugations, with substantially vertical side walls and flat top and bottom walls, are preferred over those of Joshi because the relatively constant spacing between adjacent side walls provides reduced duct flow as compared to inserts with V-shaped corrugations.

[0006] However, the formation of rectangular corrugations involves additional bending operations, with the top and bottom wall of each corrugation being defined by a pair of closely-spaced substantially 90-degree bends. The metal foil used in these inserts is very thin and therefore it is difficult to form clean bends along the edges of the top and bottom walls.

[0007] In order to ensure that the top and bottom walls of the corrugations are in contact with the plates or tubes of the heat exchanger, these corrugated heat exchange elements are usually compressed between the plates or tubes during assembly. Due to the thinness of the foil, the heat exchange elements can be easily crushed by this compression, resulting in irreparable damage to the heat exchanger. While the strength of the corrugated heat exchange element may be improved by the provision of louvers, this improvement is sometimes insufficient to resist crushing during assembly. Furthermore, in conventional louvered fins or turbulators as taught by Joshi, there is an unsupported area between the ends of the louvers and the top and bottom walls. This unsupported area is particularly vulnerable to crushing during assembly of the heat exchanger.

[0008] There is a need for corrugated heat exchange elements having improved strength, manufacturability, thermal performance and/or reduced gauge, and which preferably comprise corrugations with generally flat top and bottom walls.

SUMMARY OF THE INVENTION

[0009] In one aspect, the present invention provides a corrugated heat exchange element for a heat exchanger, the heat exchange element comprising a plurality of side walls interconnected by a plurality of top and bottom walls, wherein each of the side walls defines a plane and extends parallel to a longitudinal axis, wherein each of the side walls extends between an adjacent one of the top walls and an adjacent one of the bottom walls, and wherein longitudinal bends are formed between each side wall and the adjacent top and bottom walls such that spaces for flow of a heat exchange fluid are defined between adjacent ones of said side walls; and at least one group of adjacent louvers provided in at least some of the side walls, wherein each group of adjacent louvers is defined by a plurality of parallel slits extending between the top wall and the bottom wall of the side wall substantially perpendicular to the axis; wherein each of the adjacent louvers comprises an area of the side wall between an adjacent pair of said slits and includes: (i) a first edge extending along a first slit of the adjacent pair of slits; (ii) a second edge extending along a second slit of the adjacent pair of slits; and (iii) at least one bend located between the first and second edges of the louver which causes at least one of the edges of the louver to project outwardly from the plane of the side wall.

[0010] In another aspect, the present invention provides a corrugated heat exchange element for a heat exchanger, the heat exchange element comprising a plurality of side walls interconnected by a plurality of top and bottom walls, wherein each of the side walls defines a plane and extends parallel to a longitudinal axis, wherein each of the side walls extends between an adjacent one of the top walls and an adjacent one of the bottom walls, and wherein longitudinal bends are formed between each side wall and the adjacent top and bottom walls such that spaces for flow of a heat exchange fluid are defined between adjacent ones of said side walls; wherein each of the top walls of the heat
exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls, and wherein each of the bottom walls of the heat exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls; wherein embossments are provided in at least some of the top walls and at least some of the bottom walls of the heat exchange element; and wherein each of the embossments in the top walls cause portions of said top walls to deviate away from the top plane of the heat exchange element in a direction toward the bottom plane of the heat exchange element, and wherein the embossments in the bottom walls cause portions of said bottom walls to deviate away from the bottom plane of the heat exchange element in a direction toward the top plane of the heat exchange element.

[0011] In yet another aspect, the present invention provides a plate-type heat exchanger comprising a pair of plates secured together at their margins and spaced from one another between the margins to form a fluid flow passage, the fluid flow passage having a height and having an inlet opening and an outlet opening spaced apart along a plate axis. A corrugated heat exchange element according to the invention is received inside said fluid flow passage and is located between the inlet and outlet openings with its top and bottom walls in contact with the plates.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

[0013] FIG. 1 is a perspective view of a preferred corrugated heat exchange element according to the invention;

[0014] FIG. 2 is a cross section along line 2-2 of FIG. 1;

[0015] FIG. 3 is a cross section along line 3-3 of FIG. 1;

[0016] FIG. 4 is a cross section along line 4-4 of FIG. 1;

[0017] FIG. 5 is a cross section of a corrugated heat exchange element according to another preferred embodiment of the invention;

[0018] FIG. 6 is cross sectional end view of the corrugated heat exchange element shown in FIG. 5;

[0019] FIG. 7 is a cross section of a portion of a corrugated heat exchange element according to another preferred embodiment of the invention;

[0020] FIG. 8 is a cross section of a portion of a corrugated heat exchange element according to another preferred embodiment of the invention;

[0021] FIG. 9 is a cross section of a portion of a corrugated heat exchange element according to another preferred embodiment of the invention;

[0022] FIGS. 10 to 14 illustrate corrugated heat exchange elements according to the invention having various types of protrusions in their top and bottom walls;

[0023] FIG. 15 is a plan view of a flattened section of corrugated heat exchange element of FIGS. 1 to 4;

[0024] FIG. 16 is a plan view of a flattened section of corrugated heat exchange element according to another preferred embodiment of the invention;

[0025] FIG. 17 is a cut-away perspective view of a plate-type heat exchanger incorporating the corrugated heat exchange element of FIGS. 1 to 4;

[0026] FIG. 18 is a cross section along line 18-18 of FIG. 17;

[0027] FIG. 19 is cross section through a preferred heat exchange element according to the invention having trapezoidal corrugations;

[0028] FIG. 20 is a cross sectional end view through a heat exchange element with triangular corrugations according to the invention;

[0029] FIG. 21 is a cross section through the side wall of a heat exchange element according to another preferred embodiment of the invention;

[0030] FIG. 22 is a cross section through the side wall of a heat exchange element according to another preferred embodiment of the invention; and

[0031] FIG. 23 is a perspective view of a corrugated heat exchange element according to the invention having protrusions formed in its top and bottom walls.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0032] The following is a detailed description of preferred corrugated heat exchange elements according to the invention, as well as preferred heat exchangers in which they are used. As used herein, the term "corrugated heat exchange element" is intended to include both corrugated fins and turbulators which, as mentioned above, are structurally similar and differ primarily in the way they are incorporated into heat exchangers.

[0033] A first preferred corrugated heat exchange element 10 according to the invention is now described with reference to FIGS. 1 to 4. Heat exchange element 10 comprises a plurality of corrugations 11 extending along a longitudinal axis A, the corrugations 11 being defined by a plurality of spaced-apart side walls 12 interconnected by a plurality of top and bottom walls 14, 16. Each side wall 12 defines a plane S (FIG. 2) and extends parallel to axis A. Each of the side walls 12 has a height H and extends between an adjacent top wall 14 and an adjacent bottom wall 16 of the heat exchange element 10 and is joined to the adjacent top and bottom walls 14, 16 by longitudinal bends 18 such that spaces 19 for flow of a heat exchange fluid are defined between adjacent pairs of side walls 12. Height H is defined as the distance measured along the side walls 12 between the top and bottom walls 14, 16. Although terms such as "top", "bottom", "upper" and "lower" are used herein, it is to be appreciated that these terms are used for convenience only. The top and bottom of heat exchange element 10 are preferably indistinguishable from each other. Furthermore, it is to be appreciated that the drawings illustrating the preferred embodiments are not necessarily to scale, and certain features are exaggerated in order to better explain the invention.

[0034] In the first preferred embodiment described herein, the corrugations 11 and the spaces 19 between adjacent side walls 12 are substantially rectangular, having substantially flat top and bottom walls 14, 16 and side walls 12 which are
substantially parallel to one another along their entire height H and with longitudinal bends 18 having an angle of about 90 degrees.

[0035] The top and bottom walls 14, 16 of heat exchange element 10 are generally flat and parallel to one another and have a width W, which is defined as a transverse distance between an adjacent pair of longitudinal bends 18 through which they are joined to adjacent side walls 12. The top and bottom walls 14, 16 define respective top and bottom planes T and B of the heat exchange element 10, wherein each of the longitudinal bends 18 is located in either the top plane T or the bottom plane B. In the first preferred heat exchange element 10, all the top walls 14 are preferably located in top plane T and all the bottom walls 16 are preferably located in bottom plane B. It will, however, be appreciated that this is not necessarily the case and that the objects of the invention can be achieved where the height H of the side walls 12 is varied, for example to conform to an irregularly-shaped fluid flow passage.

[0036] At least some of the side walls 12 of the corrugated heat exchange element 10 are provided with one or more groups 20 of closely-spaced louvers 24. In the first preferred embodiment, each side wall 12 is provided with two groups 20 of louvers 24. Each group 20 of louvers 24 is defined by a plurality of parallel slits 22 formed in the side wall 12 and extending substantially between the top and bottom walls 14, 16. In the first preferred embodiment, the slits 22 are substantially perpendicular to the axis A and are spaced equidistantly from one another.

[0037] Adjacent groups 20 of louvers 24 may preferably be spaced apart by a distance which is greater than the spacing between adjacent slits 22. In the first preferred embodiment, the groups 20 of louvers 24 are separated by a dividing web 46 which is located in the plane S of the side wall 12. It will, however, be appreciated that the provision of dividing web 46 between the groups 20 of louvers 24 is not necessary.

[0038] Each of the adjacent louvers 24 within each group 20 comprises an area of the side wall 12 between an adjacent pair of slits 22 and includes a first edge 28 extending along one slit 22 and a second edge 30 extending along an adjacent slit 22. Each of the louvers 24 further comprises at least one bend located between the first and second edges 28, 30. In the first preferred embodiment, there is a single, angular bend 26 provided between the first and second edges 28, 30 of each louver 24. Preferably, the bend 26 is located approximately midway between the edges 28, 30, although this is not necessarily the case. The bend 26 extends along a line which is substantially parallel to the edges 28, 30 of the louver 24 and extends throughout substantially the entire height of louver 24. The bend 26 also defines an apex 34 of the louver 24, the apex 34 being located in the plane S of the side wall 12. The apex 34 divides the louver 24 into a substantially flat first louver wall 32 and a substantially flat second louver wall 38 which meet at the apex 34 and extend from the apex 34 to the respective first and second edges 28, 30 of louver 24.

[0039] The bend 26 defines an angle α of between the first and second louver walls 32, 38. The provision of bend 26 between the edges 28, 30 of louvers 24 causes at least one of the edges of the louver 24 to project outwardly of the plane S of the side wall 12, thereby providing gaps 40 through which the heat exchange fluid can flow through the side walls 12.

[0040] In the first preferred embodiment, the louvers 24 are of the “one-sided” type, meaning that only the first edge 28 (and the first wall 32) of each louver 24 projects outwardly of the plane S of the side wall 12, while the second edge 30 (and the second wall 38) of the louver 24 is located in plane S. Furthermore, the first edges 28 of all the louvers 24 within each group 20 project outwardly from the same side of the side wall 12. In preferred embodiments where the heat exchange element 10 is orientated such that the flow of heat exchange fluid is parallel to axis A, i.e., the “low pressure drop” orientation, the first louver wall 32 is preferably at an angle β of about 20 to 30 degrees relative to plane S, with angle α being 180-β. In the first preferred embodiment, the angles α and β are the same for all the louvers 24, although this is not necessarily the case. Furthermore, each louver 24 projects outwardly of the side wall 12 by the same amount, although this is not necessary either.

[0041] As shown in the drawings, the louvers 24 within each group 20 face in the same direction, i.e., each of the slits 22 is bounded by the first edge 28 of one of the louvers 24 and the second edge 30 of an adjacent one of the louvers 24. Moreover, the louvers 24 of the two groups 20 preferably face the same direction, and preferably project from opposite sides of the side wall 12.

[0042] FIGS. 5 to 8 illustrate corrugated heat exchange elements according to other preferred embodiments of the invention in which the louvers are two-sided, i.e., each louver projects outwardly from both sides of the side wall. Two-sided louvers provide improved heat transfer because they disrupt fluid flow along both sides of the side wall and provide better transition of fluid flow from one side wall to another than one-sided louvers.

[0043] FIGS. 5 and 6 illustrate a second preferred corrugated heat exchange element 72 according to the invention which incorporates two-sided louvers 74. Heat exchange element 72 comprises a plurality of corrugations 76 extending along longitudinal axis A, the corrugations 76 having generally the same rectangular shape as the corrugations 11 of heat exchange element 10 described above. Corrugations 76 are defined by a plurality of spaced-apart side walls 78 interconnected by a plurality of top and bottom walls 80, 82. Each side wall 78 defines a plane S and is parallel to the axis A. The side walls 78 and walls 80, 82 are joined by longitudinal bends 84, each bend 84 defining an angle of about 90 degrees and being located in a top plane T or a bottom plane B of the heat exchange element 72.

[0044] FIG. 5 is a cross section through one of the side walls 78, taken in a plane corresponding to that of FIG. 2, showing that the louvers 74 are arranged in much the same way as louvers 24 of heat exchange element 10, i.e., the louvers 74 are arranged as two groups 86 separated by a dividing web 88. Each group 86 of louvers 74 is defined by a plurality of parallel, equidistantly spaced slits 90 formed in the side wall 78 and extending between the top and bottom walls 80, 82.

[0045] Each of the adjacent louvers 74 within each group 86 comprises an area of the side wall 78 between an adjacent pair of slits 90 and includes a first edge 92 extending along
one of the slits 90 and a second edge 94 extending along an adjacent slit 90. Each of the louvers 74 further comprises a single, angular bend 96 provided approximately midway between the edges 92, 94, similar to louvers 24 described above, and extending along a bend line which is substantially parallel to edges 92, 94. The bend 96 defines an apex 98 which divides the louver 74 into a substantially flat first louver wall 100 and a substantially flat second louver wall 102 which meet at the apex 98 and extend to the respective edges 92, 94 of the louver 74. The apex 98 is preferably located in the plane S of the side wall.

[0046] The bend 96 defines an angle \( \alpha^2 \) between the louver walls 100, 102 and the bend 96 is orientated so that both edges 92, 94 of louver 74, as well as the respective louver walls 100, 102, are caused to project outwardly from opposite sides of the side wall 78, with the angles between the louver walls 100, 102 and the side wall 78 or plane S being \( \beta^2 \) and \( \beta^3 \). Where angle \( \alpha^2 \) is an obtuse angle as shown in FIG. 5, it is preferably within the range from about 150 degrees to less than 180 degrees. Angle \( \alpha^2 \) may, however, be greater than 180 degrees and may be as great as about 240 degrees. Angles \( \beta^2 \) and \( \beta^3 \) may preferably be the same or different and are greater than zero, preferably being in the range from about 20 to 30 degrees as in the embodiment of FIGS. 1 to 4.

[0047] FIGS. 7 to 9 illustrate cross-sectional views through the side walls of heat exchange elements, corresponding to the cross-sections of FIGS. 2 and 5, illustrating two-sided louvers according to other preferred embodiments of the invention. The heat exchange elements shown in FIGS. 7 to 9 embody substantially the same principles described above in connection with FIGS. 1 to 6. Therefore, these embodiments are only briefly described below, focusing on the differences from the first two embodiments described above.

[0048] FIG. 7 illustrates a side wall 104 of a corrugated heat exchange element 106 having a plurality of rectangular corrugations of generally the same shape as in heat exchange elements 10 and 72 described above. The side wall 104 is provided with two groups 108 of two-sided louvers 110 arranged on either side of a dividing web 112. In this preferred embodiment, each group 108 of louvers 110 is defined by a plurality of equidistantly spaced slits 114 formed in the side wall and extending between the top and bottom walls (not shown) of the heat exchange element 106.

[0049] Each of the adjacent louvers 110 within each group 108 comprises an area of side wall 104 between an adjacent pair of slits 114 and includes a first edge 116 extending along one of the slits 114 and a second edge 118 extending along an adjacent slit 114. Each of the adjacent louvers 110 further comprises a plurality of angular bends, specifically two angular bends 120, 122, provided between the edges 116, 118 and extending along bend lines which are substantially parallel to edges 116, 118. The individual bends 120, 122 define obtuse angles \( \gamma^1 \) and \( \gamma^2 \) and divide each of the louvers 110 into three segments: a first edge portion 124 between the first edge 116 and bend 120; a second edge portion 126 between the second edge 118 and bend 122; and a central portion 128 between the bends 120, 122. An overall angle \( \alpha^3 \) of louver 110 is defined as the angle between the first and second edge portions 124, 126 of the louver, and may preferably be the same as angle \( \alpha^2 \) described above. In FIG. 7, the angle \( \alpha^3 \) is an obtuse angle.

[0050] The bends 120, 122 are orientated so that both edges 116, 118 of louver 110 project outwardly from opposite sides of the side wall 104, with an angles \( \beta^4 \) and \( \beta^5 \) between respective edge portions 124, 126 and the side wall 104 preferably being the same as angles \( \beta^2 \) and \( \beta^3 \) described above. Although FIG. 7 illustrates louvers 110 having two angular bends 120, 122, it will be appreciated that corrugated heat exchange elements according to the invention may be constructed with louvers having more than two angular bends.

[0051] FIG. 8 illustrates a side wall 130 of a corrugated heat exchange element 132 having a plurality of rectangular corrugations of generally the same shape as in heat exchange elements 10 and 72 described above. The side wall 130 is provided with two groups 134 of two-sided louvers 136 arranged on either side of a dividing web 138. Each group 134 of louvers 136 is defined by a plurality of equidistantly spaced slits 140 formed in the side wall 130 and extending between the top and bottom walls (not shown) of the heat exchange element 132.

[0052] Each of the adjacent louvers 136 within each group 134 comprises an area of side wall 130 between an adjacent pair of slits 140 and includes a first edge 142 extending along one of the slits 140 and a second edge 144 extending along an adjacent slit 140. Each of the adjacent louvers 136 further comprises an arcuate bend 146 located between the first and second edges 142, 144 of the louver 136. In the specific arrangement shown in FIG. 8, the louvers 136 are arcuately shaped across their entire width, although this is not necessarily the case. In the embodiment of FIG. 8, an angle \( \alpha^4 \) is formed between two lines 148, 150 which intersect at a line 152 bisecting the arcuate bend into two segments 154, 156 and which are tangential to the segments 154, 156 at their midpoints. Angle \( \alpha^4 \) may preferably be the same as angles \( \alpha^2 \) and \( \alpha^3 \) described above and is shown in FIG. 8 as being an obtuse angle.

[0053] As shown in FIG. 8, the edges 142, 144 of each louver 136 extend outwardly from opposite sides of the side wall 130, with the angle \( \beta^4 \) being formed between line 148 and side wall 130 and an angle \( \beta^5 \) being formed between line 150 and side wall 130. The angles \( \beta^4 \) and \( \beta^5 \) may preferably be the same as angles \( \beta^2 \) to \( \beta^3 \) described above.

[0054] FIG. 9 is a cross section through a side wall 196 of a corrugated heat exchange element 194 having a plurality of rectangular corrugations of generally the same shape as in heat exchange elements 10, 72 and 132 described above. The side wall 196 is provided with two groups 198 of two-sided louvers 200 arranged on either side of a dividing web 202. Each group 198 of louvers 200 is defined by a plurality of equidistantly spaced slits 204 formed in the side wall 196 and extending between the top and bottom surfaces (not shown) of heat exchange element 194.

[0055] Each of the adjacent louvers 200 within each group 198 comprises an area of the side wall 196 between an adjacent pair of slits 204 and includes a first edge 206 extending along one of the slits and a second edge 208 extending along an adjacent slit 204. Each of the adjacent louvers 200 further comprises a pair of angular bends 210, 212 provided between the edges 206, 208 and extending along bend lines which are substantially parallel to edges 206, 208. The individual bends 210, 212 define obtuse angles \( \gamma^3 \) and \( \gamma^4 \) and divide each of the louvers 200 into three
segments; a first edge portion 214 between the first edge 206 and bend 210; a second edge portion 216 between the second edge 208 and bend 212; and a central portion 218 between the bends 210, 212. The central portions 218 of louvers 200 are preferably located in the plane S of side wall 196 and the bends 210, 212 are oppositely directed so that the first and second edge portions 214, 216 project outwardly from opposite sides of the side wall 196. In the preferred heat exchange element 194, the obtuse angles $\gamma^1$ and $\gamma^2$ are the same and may preferably be the same as obtuse angle $\alpha$ of heat exchange element 10 described above, which results in the first and second edge portions 214, 216 of louvers 200 being parallel to each other. It will, however, be appreciated that angles $\gamma^1$ and $\gamma^2$ are not necessarily the same.

Although the protrusions are shown in FIGS. 1 to 4 as being in the form of substantially identical ribs 54, it will be appreciated that the protrusions could be any one of a number of continuous, discontinuous, regular or irregular shapes without deviating from the present invention. FIGS. 10 to 14 and 23 illustrate corrugated heat exchange elements according to the invention having variously shaped protrusions in their top and bottom walls. In FIGS. 10 to 14, all details of louvers in the side walls are omitted for convenience and similar reference numerals are used to refer to similar elements.

FIG. 10 illustrates a heat exchange element 158 having rectangular corrugations comprising side walls 160, top walls 162 and bottom walls 164 connected by longitudinal bends 165 forming angles of about 90 degrees. The top and bottom walls 162, 164 of heat exchange element 158 are each embossed with an elongate V-shaped rib 166 extending parallel to the axis and preferably extending continuously along the entire length of the top and bottom walls 162, 164.

FIG. 11 illustrates a heat exchange element 168 embossed with an irregularly-shaped, longitudinal continuous rib 170 having portions which extend relatively close to the longitudinal bends 165 at the edges of the top and bottom walls 162, 164.

FIG. 12 illustrates a heat exchange element 172 in which the top and bottom walls 162, 164 are embossed with generally circular dimples 174 of substantially constant diameter which are spaced apart along the longitudinal axis of the heat exchange element 172. The dimples 174 are relatively large, extending proximate to the longitudinal bends 165 at the edges of the top and bottom walls 162, 164.

FIG. 13 illustrates a heat exchange element 176 in which the top and bottom walls 162, 164 are embossed with relatively large circular dimples 174 separated by smaller generally circular dimples 178.

FIG. 14 illustrates a heat exchange element 182 in which the protrusions in the top and bottom walls 162, 164 are in the form of pierced holes 184 in which the material 186 displaced from the holes 184 protrudes from the top and bottom walls 162, 164.

FIG. 23 illustrates a heat exchange element 250 comprised of a series of generally V-shaped corrugations 252 comprised of angled side walls 254 joined by curved top and bottom surfaces 256, 258. Each of the side walls 254 is provided with a plurality of louvers 260 arranged in two groups 262 separated by a dividing web 264. The top and bottom surfaces 256, 258 are provided with protrusions which are in the form of hemispheric depressions 266 having a width substantially the same as the width of the top and bottom surfaces 256, 258. In the preferred embodiment shown in the drawings, the depressions 266 of adjacent corrugations 252 are aligned with each other and with the dividing webs 264. The depressions 266 function to re-direct fluid flow away from the top and bottom surfaces 256, 258 and into contact with the louvers 260, thereby minimizing duct flow and improving heat transfer. It will be appreciated that the depressions 266 can be of any desired shape, and are not necessarily hemispherical.

FIG. 15 is a plan view of heat exchange element 10 of FIGS. 1 to 4, which has been flattened to better illustrate some preferred features of the invention. As shown, the ribs
54 are formed in the top and bottom walls 14, 16 of heat exchange element 10 and the louvers 24 are formed in the side walls 12. The longitudinal bends 18 of heat exchange element 10 are formed between the side walls 12 and the adjacent top and bottom walls 14, 16 along dotted lines 52.

As mentioned above, it is preferred that the bends 18 have a small radius so that the corrugations of heat exchange element 10 will be as close as possible to an ideal rectangular shape. In order to minimize the radius of bends 18, it is preferred that the ends of at least some of the louvers 24 and the ends of at least some of the ribs 54 extend as close as possible to the dotted lines 52 along which the bends 18 are formed, thereby causing the formation of narrow areas of relatively low rigidity (low moment of inertia) along dotted lines 52.

In heat exchange element 10, the ends of all the louvers 24 and the ends of all the ribs 54 extend close to the dotted lines 52. However, as shown in FIG. 16, this is not necessary. FIG. 16 is a plan view of a flattened heat exchange element 188 which is similar to heat exchange element 10 in that it comprises side walls 12, top and bottom walls 14, 16 and longitudinal bends 18 formed along dotted lines. The heat exchange element 188 also includes a plurality of louvers 24 and ribs 54 having ends which extend close to the longitudinal bends 18, thereby creating narrow areas of low rigidity along dotted lines 52. Heat exchange element 188 also includes a plurality of ribs 190 which are shorter than ribs 54 and a plurality of louvers 192 which are shorter than louvers 24. The relative numbers and spacing of the louvers 24, 192 and ribs 54, 190 can be varied from that shown in FIG. 16, so long as the number of full length louvers 24 and full length ribs 54 is sufficient to form the areas of low rigidity along dotted lines 52.

The relative difference in rigidity between the bends 18 and the surrounding areas containing ribs 54 and louvers 24 may be further enhanced by weakening the foils 48 along lines 52. This can be accomplished for example by providing a series of small perforations (not shown) along line 52. It will be appreciated that this feature of the present invention is not restricted to use in louvered heat exchange elements such as heat exchange element 10, but can be used in any heat exchange element having rectangular corrugations.

FIGS. 17 and 18 describe a plate-type heat exchanger 56 in which heat exchange element 10 functions as a turbulator. Heat exchanger 56 may, for example, comprise an engine oil cooler for automotive applications. It will, however, be appreciated that preferred heat exchange elements according to the invention may be incorporated into any type of heat exchanger which incorporates a fin or turbulator, including concentric tube heat exchangers, without departing from the scope of the present invention.

Heat exchanger 56 comprises a pair of plates 58, 60 secured together at their margins 62, 64 and spaced from one another to form a fluid flow passage 66. The fluid flow passage has a height which is defined by the vertical spacing between the plates 58, 60 and also has fluid inlet and outlet openings 68, 70 which are spaced apart along a plate axis P. Although heat exchanger 56 is shown as comprising only two plates 58, 60, it will be appreciated that heat exchanger 56 may also include one or more additional plate pairs and may have alternating fluid flow passages for heat transfer between two or more fluids.

As shown in FIGS. 17 and 18, the corrugated heat exchange element 10 is received inside the fluid flow passage 66 and is located between the inlet and outlet openings 68, 70 so that fluid flowing between openings 68, 70 will be forced to pass through the heat exchange element 10. Preferably, as shown in FIG. 15, the edges of heat exchange element 10 are in contact with or in close proximity to the margins 62, 64 of plates 58, 60 to prevent substantial amounts of fluid from bypassing heat exchange element 10.

Each of the side walls 12 has a vertical height which is substantially equal to the height of the fluid flow passage so as to produce intimate contact between the top and bottom walls 14, 16 of heat exchange element 10 and the plates 58, 60. Where the heat exchange element and the plates 58 and 60 are formed from a brazable metal such as aluminum, this contact permits the formation of a good brazing joint between the heat exchange element 10 and plates 58, 60, thereby providing good heat transfer. In order to provide good contact, the side walls 12 of heat exchange element 10 are preferably provided with a height slightly greater than that of the fluid flow passage 66. Thus, when plates 58 and 60 are brought together during assembly of heat exchanger 56, the side walls 12 are vertically compressed and the top and bottom walls 14, 16 of heat exchange element 10 are pressed against the plates 58, 60. As mentioned above, the vertical reinforcement provided by louvers 24 permits the heat exchange element 10 to resist deformation during compression, thereby ensuring intimate heat exchange contact between the rib 10 and the plates 58, 60. It will be appreciated that the improved resistance to deformation provided by the present invention would permit a reduction in the thickness (gauge) of the foil from which heat exchange element 10 is formed, thereby resulting in material savings.

As mentioned above, the plates 58, 60 and heat exchange element 10 may preferably be formed of a brazable metal such as aluminum. More preferably, the plates 58, 60 and/or the heat exchange element 10 may be clad with an aluminum brazing alloy which forms a filler metal when heated to a sufficiently high temperature. The filler metal flows into the gaps between the top and bottom walls 14, 16 of heat exchange element 10 and the plates 58, 60, thereby joining the heat exchange element 10 to the plates 58, 60.

In the preferred embodiment shown in the drawings, the heat exchange element 10 is orientated in the “low pressure drop” orientation in the fluid flow passage 66, i.e., with the axis A parallel to the plate axis P. In this orientation, the fluid flowing through the flow passage 66 flows between and along the side walls 12, with the louvers 24 and the embossments (ribs 54) causing flow mixing of the louver-aligned flow and the duct flow.

In other preferred embodiments, the heat exchange element 10 may be orientated in the “high pressure drop” orientation, i.e., with the axis A being transverse to the plate axis P, as shown in FIGS. 3 and 4 of Joshi. In this orientation, the fluid flowing through the flow passage 66 must flow through the louver openings in order to pass from the inlet opening 68 to the outlet opening 70. In this orientation, the angle between the louver wall 32 and the axis A may be increased so as not to unduly restrict flow through the passage 66. With the heat exchange element 10 in the high
pressure drop orientation and the overall direction of fluid flow being transverse to the axis A, it will be appreciated that the protrusions in the top and bottom walls 14, 16 do not significantly improve heat transfer.

[0078] Another preferred aspect of the present invention is now described below with reference to FIGS. 3 and 19. As shown in the view of FIG. 3, the rectangular corrugations 11 of heat exchange element 10 provide mixing of louver-aligned and duct flow along and between the side walls 12, due to the presence of louvers 24, and also along the top and bottom walls 14, 16, due to the presence of the protrusions (i.e., ribs 54). There is, however, an area 180 indicated by hatching in FIG. 3 in which there is significant duct flow. The presence of duct flow 180 has the effect of reducing heat transfer.

[0079] FIG. 19 illustrates a heat exchange element 10' which is comprised of identical elements as heat exchange element 10, and therefore corresponding numbering is used to identify corresponding elements. The only difference between heat exchange elements 10 and 10' is that the corrugations 11' of heat exchange element 10' are trapezoidal rather than rectangular. In other words, the heat exchange element 10' has been compressed in a direction transverse to axis A so as to reduce the width of the spacing between adjacent top walls 14 and between adjacent bottom walls 16. This has the effect of improving flow mixing, thereby reducing the amount of duct flow and improving heat transfer.

[0080] Although the preferred embodiments of the invention have been described with reference to heat exchange elements having rectangular corrugations, it will be appreciated that at least some of the features of the present invention can be applied to heat exchange elements having corrugations of other shapes, such as generally triangular or V-shaped corrugations. FIG. 20 illustrates such a heat exchange element 220 having V-shaped corrugations 222 comprised of angled side walls 224 joined by bends 226. The heat exchange element 220 is provided with two-sided louvers 228 which are preferably similar or identical in form to the louvers described above with reference to FIGS. 5 to 9. The ends of louvers 228 extend in close proximity to the bends 226, thereby creating narrow areas of weakness at the bends 226. By extending close to the bends 226, the louvers 228 provide support for the side walls 224 throughout substantially their entire height, thereby preventing crushing of the heat exchange element 220 during assembly of the heat exchanger, as discussed above.

[0081] Further preferred aspects of the invention are shown in FIGS. 21 and 22. FIG. 21 illustrates the side wall 230 of a heat exchange element 232, the side wall 230 having two-sided louvers 234 of generally the same shape as the louvers in FIG. 9. Obtuse angles \( \gamma \), \( \gamma' \), \( \gamma'' \) and \( \gamma''' \) are formed between the edge portions and the central portions of louvers 234. As seen, these obtuse angles increase in magnitude from left to right, causing the edge portions of louvers 234 to project outwardly from side wall 230 by a greater amount from left to right. The edges of louvers 234 define inclined lines 236, 238 which diverge away from the side wall 230 from left to right. Thus, the embodiment shown in FIG. 21 illustrates how varying the angles of the louvers walls can alter the amount by which the louvers project from the side wall.

[0082] FIG. 22 illustrates how the same effect can be achieved by varying the spacing of the slits, thereby varying the widths of the edge portions of the louvers. FIG. 22 illustrates the side wall 240 of a heat exchange element 242, the side wall 240 having two-sided louvers 244 of generally the same shape as the louvers in FIGS. 9 and 21. Obtuse angles \( \gamma \), \( \gamma' \), \( \gamma'' \), and \( \gamma''' \) are formed between the edge portions and the central portions of louvers 244, and these angles are kept constant in this embodiment. As seen, the width of the edge portions of the louvers 244 increases from left to right, causing the edge portions of louvers 244 to project outwardly from side wall 240 by a greater amount from left to right. The edges of louvers 244 define inclined lines 246, 248 which diverge away from the side wall 240 from left to right. It will be appreciated that gradually increasing the amount by which the louvers project from the side wall, as in FIGS. 21 and 22, can improve flow mixing with reduced pressure drop.

[0083] Although the invention has been described with reference to certain preferred embodiments, it is not intended to be restricted thereto. Rather, the invention includes within its scope all embodiments which may fall within the scope of the following claims.

What is claimed is:

1. A corrugated heat exchange element for a heat exchanger, the heat exchange element comprising:
   a plurality of side walls interconnected by a plurality of top and bottom walls, wherein each of the side walls defines a plane and extends parallel to a longitudinal axis, wherein each of the side walls extends between an adjacent one of the top walls and an adjacent one of the bottom walls, and wherein longitudinal bends are formed between each side wall and the adjacent top and bottom walls such that spaces for flow of a heat exchange fluid are defined between adjacent ones of said side walls; and
   wherein at least one group of adjacent louvers provided in at least some of the side walls, wherein each group of adjacent louvers is defined by a plurality of parallel slits extending between the top wall and the bottom wall of the side wall substantially perpendicular to the axis;

   wherein each of the adjacent louvers comprises an area of the side wall between an adjacent pair of said slits and includes:

   (i) a first edge extending along a first slit of the adjacent pair of slits;
   (ii) a second edge extending along a second slit of the adjacent pair of slits; and
   (iii) at least one bend located between the first and second edges of the louvers which causes at least one of the edges of the louver to project outwardly of the plane of the side wall.

2. The corrugated heat exchange element of claim 1, wherein each of the slits is bounded by the first edge of one of said louvers and the second edge of an adjacent one of said louvers.

3. The corrugated heat exchange element of claim 1, wherein the first edge of each of the adjacent louvers
projects outwardly of the plane of the side wall and the second edge of each of the louvers is located in the plane of the side wall.

4. The corrugated heat exchange element of claim 1, wherein the first edges of all the adjacent louvers in each said group project outwardly from the same side of the side wall.

5. The corrugated heat exchange element of claim 1, wherein both edges of each of the adjacent louvers project outwardly of the plane of the side wall, and wherein the first edge and the second edge of each louver project outwardly from opposite sides of the side wall.

6. The corrugated heat exchange element of claim 1, wherein a single one of said bends is provided between the first and second edges of each of the adjacent louvers, wherein the single bend is angular and extends along a bend line parallel to the first and second edges of the louver to define an apex of the louver, and wherein the apex is located in the plane of the side wall.

7. The corrugated heat exchange element of claim 1, wherein a first louver wall is defined between the apex and the first edge of the louver and a second louver wall is defined between the apex and the second edge of the louver.

8. The corrugated heat exchange element of claim 1, wherein the first and second louver walls are substantially flat.

9. The corrugated heat exchange element of claim 7, wherein the single bend defines an obtuse angle between the first and second louver walls.

10. The corrugated heat exchange element of claim 1, wherein a plurality of said bends is provided between the first and second edges of each of the adjacent louvers, wherein each of the bends is angular and extends along a bend line parallel to the first and second edges of the louver, wherein each of the bends defines an obtuse angle.

11. The corrugated heat exchange element of claim 1, wherein an overall obtuse angle is defined between a first edge portion of the louver proximate the first edge and a second edge portion of the louver proximate the second edge.

12. The corrugated heat exchange element of claim 10, wherein two of said bends are provided between the first and second edges of each said louver so as to define a first edge portion between the first edge of the louver and a first one of the bends, a second edge portion between the second edge of the louver and a second one of the bends, and a central portion between the bends, and wherein the first edge and the second edge of each louver project outwardly from opposite sides of the side wall.

13. The corrugated heat exchange element of claim 12, wherein the central portions of the louvers are substantially coplanar with the plane of the side wall.

14. The corrugated heat exchange element of claim 1, wherein said at least one bend comprises an arcuate bend between the first and second edges of the louver, wherein an obtuse angle is formed between two lines which meet along a line bisecting the arcuate bend into two segments and which are tangential to the segments at their mid-points.

15. The corrugated heat exchange element of claim 1, wherein an angle between the plane of the side wall and at least one of the edges of each louver is from about 20 to 30 degrees.

16. The corrugated heat exchange element of claim 15, wherein the angle between the plane of the side wall and at least one of the edges of each louver varies among the louvers of each said group.

17. The corrugated heat exchange element of claim 16, wherein the angle between the plane of the side wall and at least one of the edges of the louvers in each said group is progressively increased so that the louver edges extend outward to a progressively greater extent from one end of the group to the other.

18. The corrugated heat exchange element of claim 1, wherein a spacing between adjacent slits is equidistant.

19. The corrugated heat exchange element of claim 1, wherein a spacing between adjacent slits is variable.

20. The corrugated heat exchange element of claim 1, wherein each of the side walls is provided with at least two groups of adjacent louvers, and wherein adjacent groups of louvers are spaced by a distance which is greater than a spacing between adjacent slits within said groups.

21. The corrugated heat exchange element of claim 1, wherein at least some of the slits and the louvers have upper and lower ends which are in close proximity to the longitudinal bends between each side wall and the adjacent top and bottom walls, respectively.

22. The corrugated heat exchange element of claim 1, wherein each of the top walls of the heat exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls, and wherein each of the bottom walls of the heat exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls.

23. The corrugated heat exchange element of claim 22, wherein the side walls are substantially parallel to one another and substantially perpendicular to the top and bottom walls, such that the spaces between adjacent side walls are substantially rectangular in shape.

24. The corrugated heat exchange element of claim 22, wherein the side walls are angled relative to one another and wherein the top and bottom walls are substantially parallel to one another, such that the spaces between adjacent side walls are substantially trapezoidal in shape.

25. The corrugated heat exchange element of claim 1, wherein the top walls of the heat exchange element are substantially coplanar and the bottom walls of the heat exchange element are substantially coplanar.

26. The corrugated heat exchange element of claim 1, wherein the top and bottom walls of the heat exchange element are generally flat and define top and bottom planes of the heat exchange element, wherein each of the top and bottom walls has a width defined by a transverse distance between an adjacent pair of said longitudinal bends, and wherein each of the longitudinal bends is located in either the top plane or the bottom plane.

27. The corrugated heat exchange element of claim 26, wherein protrusions are provided in at least some of the top walls and at least some of the bottom walls of the heat exchange element.

28. The corrugated heat exchange element of claim 27, wherein the protrusions in each of the top walls causes a portion of said top wall to deviate away from the top plane of the heat exchange element in a direction toward the bottom plane of the heat exchange element, and wherein the protrusions in each of the bottom walls causes a portion of said bottom wall to deviate away from the bottom plane of
the heat exchange element in a direction toward the top plane of the heat exchange element.

29. The corrugated heat exchange element of claim 27, wherein the protrusions extend continuously along the longitudinal axis.

30. The corrugated heat exchange element of claim 27, wherein the protrusions are discontinuous along the longitudinal axis.

31. The corrugated heat exchange element of claim 30, wherein the protrusions comprise ribs extending transversely across the width of the top and bottom walls.

32. The corrugated heat exchange element of claim 30, wherein at least some of the ribs have opposite ends which are located in close proximity to the longitudinal bends.

33. The corrugated heat exchange element of claim 1, wherein the heat exchange element is formed from a material which is relatively weakened along said longitudinal bends.

34. The corrugated heat exchange element of claim 1, wherein the material is weakened by coining or by formation of a series of perforations located along the longitudinal bends.

35. A plate-type heat exchanger, comprising:

(a) a plurality of side walls interconnected by a plurality of top and bottom walls which are in contact with the plates, wherein each of the side walls defines a plane and extends parallel to a longitudinal axis, wherein each of the top walls and an adjacent one of the bottom walls, and wherein longitudinal bends are formed between each side wall and the adjacent top and bottom walls such that spaces for flow of a heat exchange fluid are defined between adjacent ones of said side walls; and

(b) at least one group of adjacent louvers provided in at least some of the side walls, wherein each group of adjacent louvers is defined by a plurality of parallel slits extending between the top wall and the bottom wall of the side wall substantially perpendicular to the axis; wherein each of the adjacent louvers comprises an area of the side wall between an adjacent pair of said slits and includes:

(i) a first edge extending along a first slit of the adjacent pair of slits;

(ii) a second edge extending along a second slit of the adjacent pair of slits; and

(iii) at least one bend located between the first and second edges of the louver which causes at least one of the edges of the louver to project outwardly of the plane of the side wall.

36. The heat exchanger of claim 35, wherein the heat exchange element is oriented in the fluid flow passage with the axis parallel to the plate axis.

37. The heat exchanger of claim 35, wherein the heat exchange element is oriented in the fluid flow passage with the axis transverse to the plate axis.

38. The heat exchanger of claim 35, wherein the top and bottom walls of the heat exchange element are brazed to the plates.

39. The heat exchanger according to claim 35, wherein the side walls are under vertical compression between the plates, and wherein the height of the side walls in their uncompressed state is slightly greater than the height of the fluid flow passage.

40. A corrugated heat exchange element for a heat exchanger, the heat exchange element comprising:

(a) a plurality of side walls interconnected by a plurality of top and bottom walls, wherein each of the side walls defines a plane and extends parallel to a longitudinal axis, wherein each of the side walls extends between an adjacent one of the top walls and an adjacent one of the bottom walls, and wherein longitudinal bends are formed between each side wall and the adjacent top and bottom walls such that spaces for flow of a heat exchange fluid are defined between adjacent ones of said side walls; wherein each of the top walls of the heat exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls, and wherein each of the bottom walls of the heat exchange element extends between a pair of longitudinal bends through which it is joined to adjacent ones of said side walls; wherein protrusions are provided in at least some of the top walls and at least some of the bottom walls of the heat exchange element; and

wherein each of the protrusions in the top walls cause portions of said top walls to deviate away from the top plane of the heat exchange element in a direction toward the bottom plane of the heat exchange element, and wherein the protrusions in the bottom walls cause portions of said bottom walls to deviate away from the bottom plane of the heat exchange element in a direction toward the top plane of the heat exchange element.