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(54) **Heat exchange wall member, heat exchange channel element and heat exchanger employing same.**

(57) A heat exchange wall member having a multiplicity of parallel, elongated wall projection portions formed therefrom. A multiplicity of channels formed from such wall members may be disposed in a stacked array to form a heat exchanger assembly.

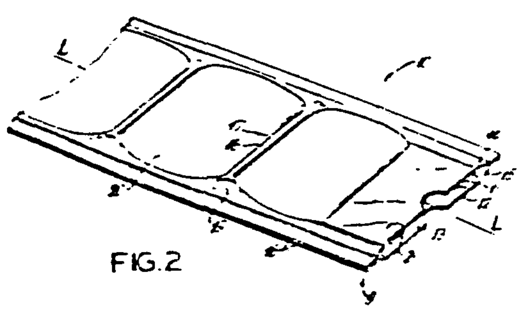

FIG.2

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This invention relates to a heat exchange channel element having a multiplicity of wall projection portions disposed on its surface and to a heat exchanger comprising channel elements formed from such wall members.

U. S. Patent No. 3,757,856 issued September 11, 1973 to L. C. Kun discloses a thin-walled, light-weight heat exchange channel element having on a portion of its wall surface isostress contours with substantially uniformly disposed unidirectional wall supporting projections. The isostress surface disclosed in the Kun patent is a continuously curved surface having a multiplicity of isostress countours wherein each contour has a multiplicity of radii with theoretically no flat segments and resembles the curved contour of a shear-free "soap bubble" membrane. The isostress contoured heat exchange channel element may suitably be formed as a longitudinally extending channel open at its extremities, whereby a first heat exchange fluid may be flowed through the interior of the channel element in heat exchange with a second heat exchange medium flowed over the exterior surface of the channel element. Such heat exchange channel elements may usefully be employed in any application where there is substantial pressure difference between the respective first and second heat exchange media and has particular utility as incorporated in an automotive radiator.

As employed in an automotive radiator or heater, a multiplicity of the Kun heat exchange channel elements are serially stacked in an array and arranged so that the wall projections on one channel element mate with and abut against corresponding wall projections on an adjacent channel element. A heat exchanger fabricated in this manner has a first set of passages defined by and bound within the channel wall members and a second set of passages defined by and disposed between the channel elements. During operation, high internal coolant pressures (of the first heat exchange medium flowed through the interior passages of the channel elements) on the order of 20 psig and higher may be accommodated, since in the stacked array the internal pressure is balanced by the support function of the adjacent channel element projections. The heat exchanger can thus be economically and quickly fabricated, with the stacked channel element assembly (heat exchanger core) being disposed within a mechanically simple load-bearing structural frame assembly.

The provision of the isostress-contoured surface in the manner of the aforementioned Kun patent permits the channel element to be readily formed of thin and lightweight materials of construction such as aluminum. For example, the channel element may be stamped from thin aluminum sheet stock having a thickness of for example on the order of 8 - 10 mils. This ability to use thin sheet metal material in fabricating channel elements has several inherent advantages, particularly in application to automotive radiators and heaters. First, the use of low material thicknesses for the heat exchanger channel elements is associated with reduced material costs and reduced material weight for the fabricated heat exchanger. The reduction in weight permits a given automobile power plant (internal combustion engine) to provide increased transportation fuel efficiency, with obvious advantage in our present economic and energy climate. Second, the use of thin wall members for the heat exchange channel element permits high heat transfer performance of the heat exchanger to be achieved. Such result is attributable at least in part to a short heat conduction path normal to the surface of the heat exchange channel element. Third, the increase in heat transfer capability of the thin-walled channel elements permits a substantial reduction in size of the fabricated heat exchanger to be achieved.

Notwithstanding the above-identified advantages of heat exchange channel elements and heat exchangers constructed in accordance with the teachings of the aforementioned Kun patent, automotive heat exchangers of such type have not yet been widely implemented in the construction of automobiles and other motor vehicles. A primary reason for this lack of implementation is associated with the characteristic external heat exchange medium pressure drop in the fabricated heat exchanger. In the normal automobile configuration, wherein air (the external heat exchange medium) flows successively through the front grill panel, the air conditioner condenser (if present), the radiator, the fan, and then by the engine block, the radiator represents a principal resistance to air flow. In this configuration, radiators constructed in accordance with the Kun teachings typically have a higher air-side pressure drop than conventional radiator designs. As a result, the Kun radiator will operate with a lower gas velocity at the primary surface of the channel element than is characteristic of conventional radiators. Such lowered air-side gas velocity in turn reduces the air-side heat transfer. Inasmuch as air-side heat transfer represents the controlling or limiting resistance to heat transfer in the radiator, the lower air-side gas velocity and heat transfer disadvantageously reduce the advantages otherwise achieved by the radiator in employing thin wall members.

Accordingly, it is an object of the present invention to provide a heat exchange wall member which may be employed to form a thin-walled, light-weight heat exchange channel element possessing the advantages of the channel element disclosed in the aforementioned Kun patent which when employed in a heat exchanger assembly, such as an automobile radiator, has more favorable air-side pressure drop performance than the heat exchanger disclosed in the Kun patent.

In its broadest aspect, the invention relates to a heat exchange wall member of thermally conductive material having a multiplicity of wall projection portions distributed across the wall member surface and extending therefrom with load-bearing end segments at their extremities, whereby the wall member may be supported abuttingly against an adjacent structural member by the load-bearing end segments of the wall projection portions.

In the improvement of the invention, the wall projection portions extend elongately on the wall member surface with the load-bearing segments thereof having an aspect ratio (d_2/d_1) of at least 10, wherein d_2 = length of the major axis of the wall projection portion load-bearing end segment measured in the base plane of the wall member and d_1 = length of the minor axis of the wall projection portion load-bearing end segment measured in the base plane of the wall member. The wall projection portions are oriented on the wall member surface with the major axes of the load-bearing end segments of the wall projection portions aligned substantially parallel to one another. In addition, the wall projection portions have a dimensional size and a dimensional relationship therebetween defined by a D dimension of between about 0.2 and 3.0 inch, a H/D ratio of between about 0.05 and 0.5, and D/d_1 ratio of between about 1.5 and 50, wherein: H = the maximum height measured perpendicularly from the base plane of the wall member to the innermost point on the wall member surface between adjacent wall surface projections; D = the spacing between the major axes of load-bearing end segments of adjacent wall projection portions, as measured perpendicularly to said major axes in the base plane of the wall member; and the base plane of the wall member is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent.

In preferred practice, the above-described heat exchange wall member is suitably employed in a heat exchange channel element including two spaced apart wall members of such type, wherein the heat exchange channel element extends longitudinally and has an elongated cross section bound by the aforementioned two spaced-apart wall members as side walls spaced apart by edge walls, the channel element having a first fluid entrance opening at one end and a first fluid exit opening at the opposite end. In this preferred embodiment, the wall projection portions extend across substantially the full width of the side wall and are oriented with the major axes of the wall projection portion load bearing end segments substantially perpendicular to the longitudinal axis of the channel element.

Another aspect of the invention relates to a heat exchanger comprising a multiplicity of channel elements of the above-described type, the channel elements being longitudinally aligned in parallel spaced relation each with a first fluid entrance opening at one end and a first fluid exit opening at the opposite end, and common inlet manifold means and common exit manifold means respectively associated with said first fluid entrance openings and said first fluid exit openings.

In a primary surface embodiment of the above-described heat exchanger, the load-bearing end segments of wall projection portions of the channel elements are shaped and arranged for mating with and abutting against load-bearing end segments of the projection portions of an adjacent channel element wall member, with the wall surface portions between the projection portions thereby forming spaces between adjacent channels through which a second fluid may be flowed in heat exchange with the first fluid.

In a preferred primary and secondary surface embodiment of the previously described heat exchanger, a multiplicity of channel elements are disposed in a stacked array with secondary surface plate-like members being disposed between adjacent channel elements with the load-bearing end segments of the wall projection portions of the channel elements being shaped and arranged for mating with and abutting against the secondary surface members, whereby the secondary surface members are maintained in thermal contact with the channel elements along the abutting load-bearing end segments thereof.

As used herein, primary surfaces are those which bound the passage walls separating the two fluids in heat exchange. The flow path between the fluids is merely the thickness of the passage wall so that heat flows substantially normal to the wall. In contrast, secondary surfaces are not in direct contact with the first heat exchange fluid but rather are substantially surrounded by only the second fluid. Accordingly, the heat flow path through the secondary surface is substantially parallel to the surface.

Figure 1 is an isometric view of a portion of a heat exchange wall member according to one embodiment of the present invention.

Figure 2 is an isometric view of a portion of a heat exchange channel element according to one embodiment of the present invention.

Figure 3 is a sectional, elevational view of a portion of the Figure 2 channel element along the longitudinal axis L-L thereof.

Figure 4 is a sectional, elevational view of the Figure 2 channel element, taken in cross section along a wall projection portion thereof.

Figures 5 and 6 show illustrative configurations of wall projection portions such as may be employed in the Figure 2 channel element.

Figure 7 is a plan view of a portion of the Figure 2 channel element, showing the geometric and dimensional features of the wall surface of the channel element.

Figure 8 is an isometric view of another heat exchange channel element according to the invention.

Figure 9 is a plan view of a portion of the Figure 8 channel element, showing the geometric and dimensional features of the wall surface thereof.

Figure 10 is a plan view of another heat exchange channel element according to the invention.

Figure 11 is an isometric view of a portion of the Figure 10 channel element, showing the details of the wall projection portions thereof.

Figure 12 is a sectional elevational view of a portion of a stacked array of channel elements of the type shown in Figures 10 - 11.

Figure 13 is a sectional elevational view of a portion of another stacked array utilizing channel elements of the type shown in Figure 10.

Figure 14 is an isometric view of a portion of a heat exchange channel element of the type shown in Figure 2., provided with a secondary surface fin at one edge thereof.

Figure 15 is an isometric view of a heat exchange channel element of the type shown in Figure 2, provided with secondary surface fins at both edges thereof.

Figure 16 is an isometric view of a channel element of the type shown in Figure 2, provided with multiple fins at both edges thereof.

Figure 17 is an elevational view of a portion of a stacked array of heat exchange channel elements of the type shown in Figure 2.

Figure 18 is an elevational view of a portion of a stacked array of heat exchange channel elements of they type shown in Figure 2, with secondary surface plate-like numbers being disposed between adjacent channel elements.

Figure 19 is an elevational view of a portion of a stacked array of heat exchange channel elements according to the invention, wherein each channel element is provided with a sequence of wall projection portions of alternately varying height.

Figure 20 is an elevational view of portions of two distinct channel elements adapted for mating with one another by means of wall projection portions with non-planar load-bearing segments.

Figure 21 is an isometric view of a portion of a heat exchange channel element according to the invention showing two types of wall projection portions with non-planar load-bearing segments.

Figure 22 is an isometric view of a stacked array of heat exchange channel elements according to another embodiment of the invention.

Figure 23 is an isometric view of a stacked array of heat exchange channel elements as shown in Figure 2 but provided with secondary surface fins at each edge thereof and with a secondary surface plate-like member disposed between adjacent channel elements, the plate-like member being provided with slatted, slotted louver-type surface distortions.

Figure 24 is a plan view of another secondary surface plate-like member, such as may alternatively be employed in the Figure 23 stacked array of heat exchange channel elements.

Figure 25 is a sectional elevational view of the Figure 24 plate-like secondary surface member taken along line A-A.

Figure 26 is an elevation view of a wind tunnel used to test automobile radiator heat exchangers.

Figure 27 is an exploded assembly drawing of a portion of a heat exchanger according to the invention, comprising a stacked array of heat exchange channel elements of the type shown in Figure 15.

Figure 28 is an isometric view of a portion of the heat exchanger assembly of Figure 27, showing the details of the headering arrangement thereof.

Figure 29 is a sectional plan view of a portion of the headering arrangement of Figure 28.

Figure 30 is an isometric view of a portion of the headering arrangement of Figure 28.

Figure 31 is a graph of convective heat transfer effectiveness factor plotted as a function of Reynold's number, for various heat exchanger embodiments of the present invention and for a heat exchanger constructed in accordance with Kun U. S. Patent No. 3,810,509

Figure 32 is a graph of heat transfer material effectiveness for radiators constructed in accordance with the present invention and a radiator constructed in accordance with the aforementioned Kun patent, plotted as a function of gas flow velocity at the face of the radiator.

Figure 33 is a graph of channel element wall member deflection plotted as a function of internal vacuum pressure and also as a function of internal buckling pressure, for a channel element according to the present invention and a channel element according to Kun U. S. Patent No. 3,810,509.

Referring now to the drawings, Figure 1 is an isometric view of a portion of a heat exchange wall member according to the present invention stamped from thin sheet metal. The wall member 11 is stamped with a surface comprising ridge projections 17 extending elongately across the top surface of the wall member with flat top surface portions 18 at the extremities of the ridge projections, the flat top surface portions 18 having an aspect ratio (d_2/d_1) of at least 10, wherein d_2 is the longitudinal dimension of the ridge projection flat top surface portion and d_1 is the transverse dimension of the ridge projection flat top surface portion. The flat top surface portions are surrounded by top surface portions 20 having a concave elevational contour. Edge surface portions 19 are formed between the unstamped margins 16 of the wall member and the aforementioned flat top surface and concave surface portions of the wall member.

Figure 2 is an isometric view of a portion of a heat exchange channel element according to the present invention. The heat exchange channel element 10 includes two spaced-apart wall members 11 and 12 of thermally conductive material bounding a fluid flow channel 13. A multiplicity of wall projection portions 17 are distributed across the wall member surface and extend from the wall member surface with load-bearing end segments 18 at their extremities, whereby the channel element may be supported abuttingly against an adjacent structural member by the load-bearing end segments of the wall projection portions.

The two spaced-apart wall members 11 and 12 of the Figure 2 channel element constitute side walls of the channel element. These side walls are spaced apart by edge walls comprising edge wall portions 14 and 15. In practice, the edge walls of the channel element may be formed separately from the side walls and joined to the latter as for example by braising or welding to form the completed channel element, however, it is more advantageous in general to form upper and lower halves of the channel element from unitary sheets of material as shown more clearly in Figure 4, so that the upper half of the channel element comprises (side) wall member 11, edge wall portion 14 and flange-like margins, and with the lower half of the channel element being similarly formed. With such integral side and edge wall construction, the upper and lower channel element halves may be joined to one another by welding, braising, adhesive bonding or other suitable joining method along the mating surfaces of the margins 16.

The side walls and edge walls of the Figure 2 channel element may suitably have a thickness of between about 0.003 and 0.25 inch. In the preferred practice of the invention, wherein the side walls and edge walls are formed of aluminum, as suitably employed in automobile radiator applications, the walls desirably have a thickness of between about 0.003 and 0.100 inch.

As shown in Figure 2, the channel element is formed in such manner that the wall projection portions 17 are provided in the form of ridges extending across substantially the full width of the side wall 11, with the wall member surface 20 between adjacent wall projection portions being concavely curved. In such configuration, the wall projection portions 17 extend elongately on the wall member surface with the load-bearing segments 18 thereof having major axes which are substantially perpendicular to the longitudinal axis L-L of the channel element. The load-bearing end segments 18 of the wall projection portions 17 intersect the edge wall portions 14, 15 of the channel element at edge wall surfaces 19, which preferably are convexly contoured as shown in Figure 3 to decrease hydrodynamic drag and pressure drop when a second heat exchange medium is flowed over the external surfaces of the channel element, from left to right as shown in Figure 4, in heat exchange with a first heat exchange medium flowing through the channel element interior flow channel 13.

The illustratively shown channel element in

Figure 2 is a portion of a longitudinally extending element having its unillustrated extremity formed in the same manner as the extremity shown. Each extremity is provided with an end section 9 having flat side wall end portions 21. By such configuration, the channel elements may be stacked in an array of such elements to form a heat exchanger core, with the side wall end portions 21 of adjacent channel elements mating abuttingly with one another in a manner as shown more fully hereinafter.

Figure 3 shows a sectional, elevational view of a portion of the Figure 2 heat exchange channel element along the longitudinal axis L-L. The features of the channel element in Figure 3 are numbered correspondingly with respect to Figure 2. As shown in Figure 3, the upper and lower wall members 11 and 12 of the channel element 10 are similarly formed with a concavely contoured wall surface between adjacent wall projection portions and with the upper and lower wall members 11 and 12 oriented with respect to one another so that the innermost point on the wall surface between adjacent wall projection portions of one wall member is vertically aligned with a load-bearing end segment of a wall projection portion of the other wall member. Thus, for example, the innermost point on the wall surface 20 of upper wall member 11 is vertically aligned with the load-bearing end segment 18a of lower wall member 12.

Figure 3 shows the geometric and dimensional characteristics of the channel element. As indicated above, the wall surface between adjacent wall projection portions in this embodiment is concavely curved; specifically, the elevational contour of such wall surface is concavely circular, i.e., the surface in elevation has a uniform radius of curvature R_1 between the load-bearing end segments of adjacent wall projection portions. The relative "depth" of the depression between adjacent wall projection portions is measured with reference to the base plane P of the wall member, which is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent. In this embodiment of the invention, all wall projection portions of the channel element extend outwardly from the wall member surface to a uniform extent, and the load-bearing end segments are flat and horizontally aligned as shown, so that the load-bearing end segments in this embodiment lie fully in the base plane P of the wall member.

The remaining dimensional parameters in Figure 3 are measured by reference to the above-described base plane of the wall member. The dimension H, which in the Figure 3 embodiment provides a measure of the "depth" of the concavely contoured surface between adjacent wall projections, is the maximum height measured perpendicularly from the base plane P of the wall member to the innermost point (i.e., the furthest point from the base plane) on the wall member surface between adjacent wall surface projections. The dimension d_1 is the length of the minor axis of the wall projection portion load-bearing end segment measured in the base plane of the wall member. In this embodiment the length of the load-bearing end segment minor axis is simply the measured lateral dimension of the load-bearing end segment and this dimension is uniform across the width of the channel element along which the load-bearing end segment elongately extends. The characteristic dimension of the load-bearing end segment in the direction of elongation of the associated wall projection portion (not shown in Figure 3), as shown more fully hereinafter, is the major axis of the load-bearing end segment. The D dimension is the spacing between the respective points of intersection of major and minor axes of load-bearing end segments of adjacent wall projection portions, as measured in the base plane of the wall member. The minimum channel clearance for the channel element is shown as dimension C_L.

Figure 4 is a sectional elevational view of the Figure 1 channel element taken in cross section at a wall projection portion 17 of the upper wall member 11. As shown, the channel element has an elongated cross section bound by the two spaced-apart wall members 11 and 12 as side walls spaced apart by edge walls formed by edge wall portions 14 and 15. The channel element disembodiment is formed from corresponding upper and lower distinct integral halves which are bonded together along the facing surfaces of peripheral flange-like margins 16. The upper and lower halves of the channel element may suitably be prepared from sheet metal stock with the illustrated surface configuration by conventional fabricating techniques such as pressing, stamping, rolling or the like. As indicated hereinabove, the upper and lower channel element halves may be bonded at their margins by soldering, braising, welding, adhesive bonding or other suitable joining technique. The surface 19 of edge wall portion 14 adjacent the wall projection 17 has an elevational contour of convex slope. Alternatively, edge wall surface 19 could be provided with a straight or concave contour. Nonetheless, the convex contour shown is generally preferred in practice, inasmuch as it allows the edge walls in the region of the wall projection portions to accommodate higher internal pressures than can be tolerated with linear or concave contours of the edge wall surface 19. Furthermore, the convex edge wall surface 19 greatly reduces the frictional drag that would otherwise be associated with a blunt edge wall.

Figures 5 and 6 are sectional, elevational views of wall projection portions having elevational contours such as have usefully been employed in practice. Figure 5 shows an elevational contour of the type shown more generally in the Figure 3 drawing, in which the side walls of the projection 17 intersect the flat load-bearing surface 18 at a sharp corner. Figure 5 shows an alternative elevational contour in which the side walls of the projection 17 intersect the flat load-bearing surface 18 with a convex contour in the region of intersection. In both the Figure 5 and 6 embodiments, the channel element exterior surface between adjacent wall supporting projections is a concave surface integral with project curvature having a radius of curvature R_1 the projection angle θ_1 shown in Figures 5 and 6 is the included angle formed between a tangent to the wall member surface at the point of intersection of the projection side wall with the load-bearing end segment of the projection and a plane parallel to the base plane of the channel element wall member. In the Figure 6 embodiment, wherein the region of intersection between the projection side wall and the flat load-bearing end segment of the projection has a convex surface contour, the surface has a radius of curvature R_2, as shown in the drawing.

With reference to Figures 5 and 6, and by way of example, illustrative dimensional parameters are set forth below in Table 1 for channel elements having projections as shown in Figures 5 and 6 and otherwise generally constructed in accordance with the channel element shown in Figures 2 - 4.

Table I

Dimensional Parameters for Heat Exchange Channel Elements Having Wall Projection Elevational Contours of Figures 5 and 6

Dimension	Figure 5 Elevational Contour	Figure 6 Elevational Contour
Wall Projection Spacing, D (in.)	0.60	0.70
Maximum Depth of Concave Wall Surface Relative to Wall Member Base Plane	0.055	0.068
Wall projection Minor Axis, d_1 (in.)	0.020	0.030
Projection Angle, θ_1 (degrees)	21.5	15.4
Minimum Channel Clearance, C_L (in.)	0.037	0.041
Contour Radius of Wall Member Surface Between Adjacent Projections, R_1 (in.)	0.792	0.829
Projection Corner Radius, R_2 (in.)	-	0.030

The foregoing dimensional values in Table I have been usefully employed in heat exchange channel elements utilized to fabricate automotive radiator heat exchangers.

Figure 7 is a plan view of a portion of a heat exchange channel element shown in Figures 2 - 4, showing the dimensional and geometric characteristics of the channel element in greater detail. The various structural features of Figure 7 are numbered correspondingly with

Those of Figures 2 - 4. As shown in Figure 7, the wall projection portions 17 extend elongately on the wall member surface with the load-bearing segments thereof having a major axis cf length d_2, as measured in the base plane of the channel element wall member along the direction of elongation of the wall projection portion of the channel element. The length of the major axis of the wall projection load-bearing end segment thus provides a measure of the extent of the wall support bearing surface provided at the extremity of the wall projection portion, between the extremities of the load-bearing end segment surface at opposite edges of the channel element as shown in Figure 7 where the extremities of the load-bearing end segment surface intersects the edge wall surface portions 19. Likewise, the minor axis d_1 is a measure of the dimensional extent of the wall projection load bearing surface along a direction transverse to the direction of elongation of the wall projection (substantially perpendicular to the channel element longitudinal axis in the embodiment of Figure 7). The major axis and the minor axis of the wall projection load-bearing end segment are measured in the base plane of the wall member. In embodiments of the invention such as are shown in Figures 2 - 7, the wall projection load-bearing end segments of the channel element lie in the base plane of the channel element wall member, so that the major and minor axes of the load-bearing end segment are merely the length and width dimensions of the end segment.

In accordance with the invention, the wall projection portions extend elongately on the wall member surface of the channel element with the load-bearing segments thereof having an aspect ratio (d_2/d_1) of at least 10. The reason for such minimum value of the aspect ratio is to provide a sufficient extent of elongation so that the channel element wall member has sufficient rigidity to accommodate high internal coolant pressure levels. As a result, channel elements of the type shown in Figure 2-7 are able to be employed with significantly higher internal coolant pressures than have been achievable in thin-walled channel elements of the prior art, including those of Kun U. S. Patent No. 3,757,856. Such characteristic is particularly advantageous in application of the channel element of the instant invention to fabrication of automobile radiators, since in such application increased coolant pressures serve to increase the boiling temperature of the coolant, thereby permitting the radiator to accommodate higher engine temperatures and to function with the same degree of efficiency in a more compact radiator configuration. In preferred practice, the aspect ratio d_2/d_1 is at least 30.

As shown in Figures 2 - 7, the wall projection portions of the channel element in accordance with the present invention are oriented on the wall member surface with the major axes of the load-bearing end segments of the wall projection portions aligned substantially parallel to one another. The distribution of wall projection portions across the wall member surface of the channel element is characterized by dimension D, which equals the spacing between the major axes of load-bearing end segments of adjacent wall projection portions, as measured perpendicularly to the major axes in the base plane of the wall member. As indicated hereinearlier, the base plane of the wall member is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent. In the broad practice of the invention, the wall projection portions on the wall member surface of the channel element have a dimensional size and a dimensional relationship therebetween defined by a D dimension of between about 0.2 and 3.0 inch, a H/D ratio of between about 0.05 and 0.5, and a D/d_1 ratio of between about 1.5 and 50. The upper limit on the D dimension of 3.0 inch is imposed because at spacings above such value the heat exchange area per cubic foot of heat exchange volume of the channel element or stacked array of channel elements decreases disproportionately and the ability of the channel element wall member to accommodate increasing differential pressure across the wall is undesirably reduced. The lower limit on the D dimension about 0.2 inch dictated by pressure drop considerations for the external heat exchange medium flowed over the exterior surfaces of the channel element; at spacing values of less than about 0.2 inch, the pressure drop tends to become unduly large, so that the advantages of the invention, of maintaining low external heat exchange medium pressure drop consistent with high heat transfer performance, are increasingly difficult to achieve. H, the maximum height measured perpendicularly from the base plane of the wall member to the innermost point on the wall member surface between adjacent wall surface projections, is related to the aforementioned D dimension by the constraint that the ratio H/D is between about 0.005 and 0.5. The parametric range of values permissible for the H/D ratio is associated with maximum and minimum values which are based on considerations of the maximum and minimum allowable values for the D dimension, as discussed above, and the maximum and minimum allowable values for the parameter H. The maximum allowable value for H in a given application is determined by the requirement of achieving a necessary minimum level of heat exchange area per cubic foot of heat exchange volume, as necessary for efficient heat transfer. Similarly, the lower limit on H is imposed by heat exchange surface area considerations, however, in this case the limit is dictated by the incremental cost required in providing the contoured surface as compared with the additional area provided by such contoured surface when compared with an uncontoured planar wall member. All of these various considerations are effectively accommodated by a H/D ratio of between about 0.05 and 0.5.

Similarly, D/d_1 ratio of between about 1.5 and 50 is based on the various considerations for maximum and minimum values of D, as discussed above, and maximum and minimum allowable values of d_1. Depending upon the end use of the channel element, the minor axis dimension on the load-bearing surface of the wall projection portion, d_1 is fixed by two competing considerations. As the value of d_1 increases, the maximum allowable differential pressure across the channel element wall member will increase, while the available surface area of the channel wall element for heat exchange will decrease. As a result, in any application of the channel element of the invention, the relative degree of importance of the heat exchange considerations as opposed to strength considerations for the channel element will set the upper limit on the value of d_1. The lower limit on the minor axis dimension of the projection load-bearing segment is determined by manufacturing tolerances, by strength considerations, i.e., the need to insure that the load which is concentrated at the load-bearing surface does not produce stresses sufficient to deform or rupture the walls of the channel element, and by fabrication limitations associated with the material thickness of the channel element wall member. These various considerations may be effectively accommodated under D/d_1 ratio of between about 1.5 and 50.

To meet the specific heat exchange requirements for radiators of internal combustion engines, the channel element is preferably formed with the following geometric and dimensional characteristics: an H value of between about 0.035 and 0.080 inch; a D value of between about 0.4 and 1.1 inch; and a d_1 of between about 0.01 and 0.05 inch. For automotive radiators, the H/D ratio is preferably between about 0.05 and 0.4, on the basis of the previously discussed considerations applicable to such parameter.

Referring again to Figures 5 and 6, the elevational contour of the wall member projection portions should be such as to maintain at acceptable levels in both the projection portions and the other portions of the channel wall. Preferably, the projection portions should have an elevational contour such that the ratio θ/R is between about 4° and 2500° per inch, and most preferably between about 4° and 100° per inch for a wall member wherein the wall surface between adjacent projection portions has an elevational contour which is concavely circular, i.e., the radius of curvature of the wall member surface between the load-bearing end segments of adjacent wall projections is constant. As discussed earlier herein, θ is the included angle between a tangent to the wall projection side wall at the point of intersection with the load-bearing segment of the projection and a plane parallel to the base plane of the wall member. In terms of the aforementioned θ/R_1 ratio, and as applicable to the broad practice of the present invention, R_1 is the minimum radius of curvature of the wall projection side walls. The minimum radius of curvature R_1 may be measured readily conveniently by the well-known optical comparator. In general, if θ is relatively low, then R_1 (the minimum radius of curvature) can be relatively small. If the wall projection angle θ is large in value, then R_1 should also be relatively large in magnitude. The upper limit on the θ/R_1 ratio of 2500°/inch is based on wall projection portions having a truncated conical elevation contour, such as is shown in Figure 10 - 12, described hereinafter in greater detail. For a wall projection having a truncated conical elevational contour, the magnitude of the projection angle θ should not exceed 35°. The lower limit for θ/R_1 of 4°/inch is based on a wall projection having a concavely curved projection side wall contour and a flat load-bearing end segment, with minimum contour height H and the largest value of spacing D permitted based on structural stress considerations.

Figure 8 shows an isometric view of a channel element according to another embodiment of the invention. The channel element includes two spaced-apart wall members 111 and 112 of thermally conductive material, e.g., aluminum, bounding a fluid flow channel 113 and having a multiplicity of wall projection portions 117 distributed across the wall member surface 120 and extending therefrom with load-bearing end segment 118 at their extremities.

The two spaced-apart wall members 111 at 112 constitute side walls of the channel element which are spaced apart by edge walls made up edge wall portions 114 and 115. As shown, the channel element is fabricated from upper and lower halves, with the upper half of the channel element being stamped from a single piece of sheet metal,so that the upper and lower side walls and their associated edge wall portions are formed from a unitary sheet of material. The channel element halves so formed are provided with peripheral margins 116 which are not deformed and thus permit mating and bonding of the upper and lower channel element halves in the manner previously described in connection with Figure 2 herein. The channel has a first fluid entrance opening 131 at one end and a first fluid exit opening 130 at the opposite end, with the end sections 121a and 121b of the channel element being characterized by flat side walls which form mating surfaces for stacking of a series of channel elements on top of one another in an array to form a heat exchanger core assembly, as descirbed hereinafter in greater detail.

Figure 9 is a plan view of a portion of the channel element 110 of Figure 8, showing the dimensional characteristics thereof. As shown, each of the wall surface projection portions 117, in contrast to the wall projection portions of the embodiment of Figures 2 - 7, do not extend substantially across the full width of the channel element, but rather only a portion of the width.

Nontheless, despite its reduced elongational extent relative to the wall projections of Figures 2 - 7, the pro- of the channel element of Figures 8 - 9 are structurally similar to those previously described herein, having a major axis d_2 which is at least 10, and preferably 30, times the magnitude of the minor axis d_1. As in previous embodiments, the spacing between adjacent channel elements is measured by dimension D, which equals the distance between the major axes of load-bearing end segments of adjacent wall projection portions, as measured perpendicularly to the major axes in the bas plane of the wall member. The wall projection portions 117 in the Figures 8 - 9 embodiment, as in the preceding embodiments, elongately extend across the channel element in a direction substantially perpendicular to the channel element longitudinal axis L - L.

Figure 10 is a plan view of a portion of another channel element according to the invention, which differs from the embodiments previously described in that the wall surface between adjacent wall projection portions 217 is substantially planar. The channel element 210 is provided with extremities comprising a planar channel element end section 221 for mating and bonding adjacent channel elements when the channel elements are disposed in a stacked array. A first fluid opening 230 is provided at the tube end for introduction or egress of a first heat exchange fluid into or out of the fluid flow channel bounded by the chanel element wall members. The channel element may be formed from discrete upper and lower halves in the manner previously described, with mating and bonding of the respective halves to one another along peripheral margins 216. The surface of the channel element wall member 220 is planar and a multiplicity of wall projection portions 217 are distributed across the wall member surface, extending therefrom with load-bearing end segments 218 at their extremities.

Figure 11 is an isometric view of a portion of the heat channel element of Figure 10, showing the details of the wall member projection portion thereof. The channel element includes two spaced-apart wall members 220 as side walls spaced apart from one another by edge 214 and 215 so that the side and edge wall members together bound and enclose a fluid flow channel 213, whereby a first heat transfer fluid medium may be flowed through the interior channel 213 in heat exchange with a second heat transfer medium flowed over the exterior surfaces of the channel element. On the exterior surface of the channel element wall member 220 is disposed a multiplicity of wall projection portions 217 having flat load-bearing surface 218 at their extremities. The channel element shown in Figure 11 differs from those of Figure 2 - 9 in that the former has a wall surface between adjacent projections which is planar and not continuously curved as in the preceding described embodiments. The wall projection portions in the Figure 12 embodiment may be formed from the wall members as by stamping, pressing, rolling and the like, as in the case of the preceding described embodiments, or, alternatively, the wall projection portions may be provided as separate and distinct structural elements which are bonded or otherwise affixed to the flat wall member surface of the channel elements. The provision of the wall member 220 as a separate and distinct structural part of the channel element from the wall projection portion 217 permits the fabrication of the channel element to be potentially simplified, inasmuch as no stamping, rolling or other forming step is necessary for the side wall surface. Thus, for example the channel element could be fabricated from a flattened tube by soddering, braizing, or otherwise joining the projection portion 217 to the exterior wall member surface 220, with the wall projection portion being machined, cast or otherwise constructed by any suitable forming method.

Figure 12 is an elevational view of a stacked array of two channel elements of the type shown in Figures 10 and 11,. showing the abutment and mating of the load-bearing segments of wall projections portions of adjacent channel elements in the array. The channel elements 210 and 210a are each provided with a multiplicity of wall projection portions 217 distributed across their wall surfaces. Each wall projection portion 217 is provided with a flat load-bearing surface 218 at its extremity, so that the projection portions have a truncated conical elevational contour characterized by a wall projection angle θ of preferably less than 35° and a ratio θ/R_1 suitably having a value of between 4° and 2500° per inch, as discussed earlier herein. In this embodiment, the minimum radius of curvature of the wall projection, R_1, is measured in the region of the intersection of the projection side wall and the flat surface 220 of the channel element wall member.

In the Figure 12 stacked array of channel elements, each channel element is structurally identical with the wall projection portions of the topside and bottomside of the channel element being vertically aligned. In this array, the load-bearing end segments of wall projection portions of the channel element are shaped and arranged for mating with and abutting against load-bearing end segments of the projection portions of the adjacent channel element side wall, so that the wall surface portions between the projection portions thereby form spaces between adjacent channel through which a second fluid may be flowed in heat exchange with first fluid passed through the interior channel of the respective channel elements.

In contrast to the Figure 12 stacked array, Figure 13 shows an array wherein the channel elements are formed with their upper and lower wall projections staggered with respect to another. Apart from such difference, the channel elements in Figure 13 are generally similar in construction to the channel elements employed in the array of Figure 12, the choice alternative Figure 12 and Figure 13 array configurations being a matter of choice to the heat exchanger designer in a given application.

Figure 13 is an isometric view of a channel element according to the present invention, formed in a manner similar to that shown and described in connection with Figures 2 - 7, but with a secondary surface fin at one edge thereof. Corresponding features of the Figure 14 channel element are numbered correspondingly with respect to Figures 2 - 7, but with the respective reference numbers in Figure 14 being numbered with respect to the Figures 2 - 4 drawings by addition of 200 to the corresponding reference number in Figures 2 - 4. The numbering of Figure 14 is also common to Figures 15 and 16, as hereinafter described. The secondary surface fins shown in Figures 14 - 16 are of a type as described in Kun U. S. Patent No. 3,810,509 and also disclosed and claimed in Kun U. S. Patent No. 3,845,814. In all three embodiments of Figures 14 - 16, the secondary surface fin members are joined to the primary surface channel element at the edge wall margins 316 and, in practice, it may be desirable to form the channel member with the secondary surface fin member integral with one or the other of the halves of the channel element.

In the Figure 14 embodiment, a single fin member 350 is joined to the channel element at one edge thereof along margin 316. The fin is, consistent with the teachings of the above-mentioned Kun patents, suitably provided with slots or louvers 351 along substantially the entire length of the fin. The channel element shown in Figure 15 represents a modification of the Figure 14 channel element wherein the latter is provided with an additional fin 352 having louvered surface distortions 353 distributed across its surface along the length thereof, the additional fin being provided on the opposite edge wall from the first fin 350. In the Figure 16 embodiment, the channel element is provided with dual fins 354 and 356 at its opposite edges, the fins having surface distortions 355 and 357 in the form of louvered slots of the type described previously in connection with Figures 14 and 15. In Figures 14 - 16, the end section of each channel element is finless, so that when the channel elements are stacked in array to form a heat exchanger core assembly, they can be easily headered in the heat exchanger final assembly by prior art headering means. The fins in the Figures 14 - 16 embodiments can be separately attached to the longitudinal edge of the channel element, as for example by welding or braizing, but, as mentioned, the fins are preferably integral with the edge walls of the channel elements. Such integral construction greatly improves the heat transfer performance of the fins.

Figure 17 is an elevational view of a portion of a stacked array of heat exchange channel elements of the type shown in Figures 2 - 7. The stacked array 400 is made up of heat exchange channel elements 110 to form a heat exchanger core assembly. The channel elements in the Figure 17 array are longitudinally aligned in parallel spaced relation, i.e., to provide spaces between adjacent channels through which second fluid may be flowed in heat excha. ge with a first fluid being conducted through the channel interior passages. Each channel element has a first fluid entrance opening at one end and a first fluid exit opening at the opposite end, as previously described. The channel elements 410 in the array have wall projection portions 417 having load-bearing end segments which are shaped and arranged for mating with and abutting against load-bearing end segments of the projection portions of an adjacent channel element side wall, with the abutting load-bearing surfaces of the channel element facing projections being adhesively bonded to one another by bonding medium 402. Such bonding of the mating and abutting load-bearing surfaces of the channel element wall projections is not essential in the practice of the invention, and in some instances it is preferable to mate an abut the opposed wall projection end segments against one another without any interposed bonding medium. The end sections 421 of the channel element in the stacked array are of enlarged cross section relative to the intermediate sections of the channel elements and, as previously described, are provided with flat side wall portions which permit mating of adjacent channel elements in the manner shown. In practice, it is generally desirable to adhesively bond the channel element in section flat side wall portions to one another by adhesive bonding medium 401, so as to insure leak tightness of the associated inlet or outlet face of the stacked array at the extremities of the tubes, i.e., so that the first fluid introduced to or withdrawn from the channel element at its extremity does not leak out of the heat exchanger between adjacent channel element end section. The bonding media 401 and 402 may suitably comprise an epoxy or other conventional adhesive material.

Figure 18 is a modification of the form of channel element stacked array shown in Figure 17. In the Figure 18 array, the multiple channel elements 410 are disposed in the stacked array 400 with secondary surface plate-like members 403 being disposed between adjacent channel elements with the load-bearing end segments 418 of the wall projection portions 417 of the channel elements being shaped and arranged for mating with and abutting against the secondary surface members, whereby the secondary surface members are maintained in thermal contact with the channel elements along the abutting load-bearing end segments thereof. The secondary surface plate-like member 403 may be anchored in the stacked channel element assembly by bonding same between the end section facing side walls of the channel element end sections 421 as shown, with the extremity of the plate-like member being embedded in the adhesive mass 401 bonding the adjacent channel elements sections. In this embodiment, the secondary surface plate-like member is then held in place compressively along the intermediate section of the channel element by the frictional compressive contact of the channel element wall projection end segment against the plate-like member. As shown in Figure 18, the secondary surface members may suitably be substantially planar.

Figure 19 is an elevational view of a stacked array of channel elements according to another embodiment of the invention, wherein each channel element is characterized by an alternating series of projections having different heights. The portion of the array shown comprises portions of channel elements 50 and 51, the former having alternating wall projections 52 of greater height and an alternating series of wall projections 54 of lesser height. The taller projections 52 of channel element 50 mate and abut at their extremities with shorter wall projection portions 53 of channel element 51. Correspondingly, shorter wall projections 54 of channel element 50 mate and abut at their load-bearing extremities with taller wall projections 55 of channel element 51. In this manner, the sequential projections of varying height mate abuttingly with complimentary projections of the adjacent channel element so that the channel elements are oriented parallelly with respect to one another, i.e., so that their longitudinal axes are parallel with respect to one another. The load-bearing extremities of all of the wall projections are flat and parallel to the channel element wall surface between adjacent wall projections.

As to characterization of the channel elements in the Figure 19 stacked array, it is seen that each channel element has associated therewith two base planes, base plane P_1 associated with the shorter wall projections of the channel element and base plane P_2 associated with the taller wall projections of the channel element. As defined hereinearlier the base plane of the channel element wall member is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent. As a result of the fact that two channel elements are associated with the channel element, the channel element likewise is characterized by two values of the H parameter, the maximum height measured perpendicularly from the base plane of the wall member to the innermost point on the wall member surface between adjacent wall surface projections. Thus, the H value associated with base plane P_1 is H_1 and the H value associated with base plane P_2 is H_2. Despite the fact that each channel element thereby is characterizable by two discrete values of the H parameter, each value must satisfy the dimensional criteria of the invention, e.g., the H/D ratio must be between about 0.05 and 0.5. It will be apparent that the D spacing parameter will have the same numerical value as measured in either base plane associated with adjacent wall projections of different height, when the major axes of the wall projections under consideration are projected into the given base plane.

Figure 20 is an elevational view of two aligned channel elements 60 and 61 adapted for mating with one another along the surfaces of their load-bearing end segments. As shown, channel element 60 has disposed on its upper wall member surface wall projections 65 having a male load-bearing end segment 72 with a minor axis of length D_1, as measured by the projected length of such minor axis in base plane P_1 containing the extremities of the wall surface projection on the upper wall surface of the channel element. On the lower wall member surface of channel element 60 are disposed wall projection portions 66 having female load-bearing surfaces 71 at their extremities, with the outermost extremities of the wall projection portions lying in base plane P_2. As shown by the Figure 20 embodiment, the H dimension on the upper surface of the channel element, H_u, may be different from that associated with the lower wall surface, H_1. The channel element 61 in the Figure 20 array is similarly provided with wall projection portion 67 on its upper surface having male load-bearing end segements 69 and wall projection portion 68 on its lower wall member with female load-bearing segments at their extremities. In this manner, the adjacent channel element 60 and 61 may be mated with one another so that the male and female load-bearing surfaces 69 and 71 of associated wall projections 67 and 66 interfit with an abut against one another.

Figure 21 is an isometric view of a portion of a heat exchange channel element according to another embodiment of the invention, having two distinct alternative configurations disposed on its upper wall member surface. The channel element 74 includes two spaced apart members 78 and 79 of thermally conductive material bounding a fluid flow channel 77 and having the wall section portions 80 and 82 disposed on its wall member surface 75 and extending therefrom with load-bearing end segments 81 and 83 respectively at their extremities, whereby a channel element may be supported abuttingly against an adjacent structural member by the load-bearing end segments of the wall projection portions. The wall members 78 and 79 constitute side walls of the channel element spaced apart by edge walls 76. Each of the wall projection portions 80 and 82 extend elongately on the wall member surface 75 across the width of the channel element along a direct substantially perpendicular to the longitudinal axis L-L of the channel element.

The load-bearing end segments of the wall projection portions shown in Figure 21 differ from those previously described in that the load-bearing surface as a continuously varying elevation along the major axis direction of the wall projection, the first wall projection 80 having a load-bearing surface 81 which is undulate in elevational contour along the major axis direction, while the second wall projection 82 has a load-bearing surface 83 is of saw-tooth form along the major axis direction of the projection. Where the elevational contour of the wall projection load-bearing end segment is not flat and wholly within the base plane of the wall member, the length d_2 of the major axis of the wall projection portion load-bearing end segment is measured as the projected length of the major axis in the base plane of the wall member, in the same manner that the non-linear elevational contour of the load-bearing end segment in the minor axis dimension is measured as the projected length of the minor axis, or, more simply, as the projected width of the load-bearing surface in the base plane of the channel element, as shown in Figure 20.

Figure 22 is an elevational view of a stacked array of heat exchange channel elements according to another embodiment of the invention. As shown, the stacked array 450 comprises stacked channel elements 456, 457 and 458. Each channel element includes spaced-apart wall members comprising upper wall member 451 and lower wall member 452, each formed in accordance with the invention having ridge wall projection portions 453 extending elongately across the channel element substantially from edge to edge thereof. Each ridge projection has a load-bearing segment 454 at its extremity, with adjacent ridge projections being spaced apart from one another by interposed concave surface portions 455. In this manner, the channel elements are "nested" with the ridge projection load-bearing segments 454 bearing against the crest of the concave surface portion 455 of an adjacent channel element. Such an arrangement permits very close stacking of the constituent channel elements and thereby provides a highly compact heat exchanger assembly.

Figure 23 is an isometric view of a portion of a stacked array of heat exchange channel elements according to the invention, as interleaved with secondary surface plate-like members to form a heat exchanger core assembly. The heat exchanger core assembly 500 comprises a multiplicity of channel elements 510 of a type similar to that shown in Figure 15. The structural features of the primary surface of the channel element is numbered correspondingly with respect to Figure 2 by addition of 500 to the corresponding reference numerals of Figure 2. The secondary surface fins of the channel elements are numbered correspondingly with respect to Figure 15 by addition of 200 to the corresponding reference numerals for the secondary surface fins in Figure 15. In the stacked array, a multiplicity of channel elements are disposed with secondary surface plate-like members 503 being disposed between adjacent channel elements with the load-bearing end segments of the wall projection portions of the channel elements being shaped and arranged for mating with and abutting against the secondary surface members, whereby the secondary surface members are maintained in thermal contact with the channel elements along the abutting load-bearing end segments thereof. The secondary surface plate-like members in this embodiment have a multiplicity of surface distortions 560 distributed across portions of their surfaces which are not in abutting contact with channel element load-bearing segments. More specifically, these plate-like member distortions comprise parallel slats and slotted apertures arranged in a louvered configuration across the width of the secondary surface member.

Figure 24 is a plan view of another secondary surface plate-like member, such as may alternatively be employed in the Figure 23 stacked array of heat exchange channel elements. The plate-like member shown in Figure 24 has been found particularly useful in the practice of the invention wherein the heat exchange channel elements are employed to form a radiator heat exchanger for automotive vehicles. In this plate-like member configuration, the surface 606 of the plate member 603 alternatively punched in opposite directions perpendicular to the plane of the plate so that rectangular strips of metal are displaced therefrom to form successive depressed portions 604 and raised portions 605.

Figure 25 is sectional, elevational view of the plate-like member of Figure 24, taken along line A-A thereof. As shown in Figure 25, the raised portion 605 and depressed portions 604 are punched in such manner that respective portions are parallelly aligned in elevational view with the undeformed surface 606 of the plate member 603. This form of surface distortions of the plate-like secondary surface member permits highly efficient heat transfer along the gas flow path traversing the plate member in the direction shown in Figure 23.

Figure 26 is an elevation view of a wind tunnel for testing performance of heat exchangers, which was employed to evaluate automobile radiator exchangers constructed according to the present invention comparatively against radiator heat exchangers of the prior art, with results as hereinafter described in greater detail.

The wind tunnel of Figure 26 is used to regulate the rate and temperature of an air flow through the passages formed between adjacent heat exchange channel elements in the radiator heat exchanger being tested. Air entering the tunnel was first passed through a calibrated orifice 760, which measures the air volume flow into a four cubic foot plenum chamber 761, and then fed through flow straightening screens 762 into a tapered adapter sections 763. The adapter section 763 was provided to effect a smooth transition in the air flow between the plenum chamber 762 and a one square foot wind tunnel duct 764 coupled to a test radiator 765. A blower (not shown) was positioned downstream of the radiator for controlling the ~~air~~ flow therethrough. The heated air from radiator 765 was either exhausted via damper 766 or recirculated into the test room via damper 767 so as to provide a degree of temperature control within the room. To reduce the air flow rate through the radiator, control damper 768 was coupled downstream of exiting air flow radiator 765. The tapered adapter section 763 and the flow straightening screens 762 are employed to keep velocity variation through the test radiator 765 at a minimum. Velocity profiles and pitot tube readings made over the frontal area of different test radiators 765 indicated that the air velocity variations for all the radiators tested was insubstantial. One ———————————————

manometer 770 was positioned as shown in the test circuit and employed to measure air pressure drop. Two grids, 772 and 773, containing four thermocouples, each of which was placed in the center of one-quarter of the flow passage area of the radiator 765, measured the average inlet and exit air temperature through the test radiators765. A Brown multipoint chart recorder (not shown) and a Rubicon potentiometer (not shown) were coupled to the grids and recorded the thermocouple heatings. Thus, an accurate test circuit was provided for measuring the heat transfer capacity of the test radiators. As indicated above, test results based on evaluation of heat exchangers constructed in accordance with the present invention and heat exchangers constructed with the prior art, as derived from evaluation of the various test heat exchangers in the wind tunnel apparatus of Figure 24 are presented and discussed in detail hereinafter.

Figure 27 is an exploded assembly drawing of a portion of a heat exchanger according to the invention, comprising a stacked array of heat exchange channel elements of the type shown in Figure 15. As shown, the heat exchanger assembly comprises a stacked array 850 of heat exchange channel elements 851. Each channel element has a longitudinal axis and is bounded by thermally conductive pressure withholding walls, with a first fluid entrance opening at one end, a first fluid exit opening at the opposite end, and end sections each having a cross-section bounded by flat side walls and by edge walls comprising edge wall portions extending outwardly from the side walls and convergently with respect to each other, with the outermost ends of the edge wall portions being contiguous and coextensive with respect to one another to form a leak-tight edge wall. Adjacent channel elements in the array are stacked with their end section side walls in wall to wall contacting relationship and their end section edge walls in alignment to form a first fluid entrance face at one end of the array and a first fluid exit face at the opposite end of the array. Each face has a perimeter defined by edge wall ends 854 of the stacked channel elements and outermost side wall ends 855 of the outermost channel elements 852 and 853 in the array. The pressure withholding walls of adjacent channel elements in the interior of the array are disposed in spaced relationship with respect to each other for flow of a second fluid through the array in the space between the channel elements in heat exchange with the first fluid. The heat exchanger assembly shown in Figure 25 is of the cross-flow type and is constructed and arranged for flow of the second fluid through the array in a direction normal to the longitudinal asis of the channel elements. The channel elements are disposed in the stacked array with their longitudinal axes lying in a common plane.

In the preferred practice of the present invention, in order to achieve a highly compact exchanger configuration with a high level of heat transfer capability per unit volume of the exchanger, the stacked array contains at least 40 channel elements per foot width thereof, with the width of the stacked array being measured in the aforementioned common plane in a direction perpendicular to the channel element longitudinal axes. Inlet header means are joined in flow communication with the first fluid entrance face for introduction of first fluid to the channel elements, and an outlet header is joined in flow commincation with the first fluid exit face for withdrawal of the first fluid from the channel elements. The channel elements 853 are provided with secondary surface fins 856 having louvered surface distortions 857 thereon.

The headering arrangement in the Figure 27 assembly includes sealing members 858 extending along the end section edge walls of the channel elements at each side of the stacked array. Each sealing member has a bearing surface with a generally corrugated contour of grooves 859 and interposed ridges 860 with each of the grooves shaped so as to surround and abut the edge wall of a single channel element of the array with the interposed ridges extending inwardly and abutting the facing edge wall portions of adjacent channel elements. The bearing surface of each sealing member is bonded to the abutted channel element edge walls associated therewith, and suitably has a length as measured parallel to the channel element longitudinal axes of at least 0.2 inch which is substantially greater than the thickness of the sealing member as measured perpendicular to the channel element longitudinal axes at a lower extremity of the grooves in the bearing surface thereof.

In this headering arrangement, clip members 869 are provided having a transversely extending first segment 870a leak-tightly abutting the outer end 858a of the sealing member 858, a longitudinally extending second segment 870b integrally joined to the transversely extending first segment and adhesively bonded to an exterior surface of the sealing member, and a third end segment 871 integrally joined to the longitudinally extending second segment 870b. The header tank means in Figure 27 comprise a header tank member 874 having enclosure end wall 877 and side wall 875, 876 portions and a transversely outwardly extending flange portion 880 at an end of each side wall portion. The header tank member is provided with conduit 881 for first fluid introduction to or discharge from the heat exchanger assembly. When header tank member 874 and clip member 869 are disposed in position as assembled, the third end segment 871 of the clip member is deformed contiguously around the transversely outwardly extending flange portion 880 of the header tank member to secure the header tank member in position.

The heat exchanger assembly of Figure 27 features a tie bar structural support member 866 which is disposed against the side wall of the outermost channel element 858 in the stacked array, to absorb the outwardly directed pressure exerted by the stacked array in operation. The tie bar 866 is structurally coupled with angle bracemember 861 in the heat exchanger assembly. As shown, angle brace member 861 comprises a longitudinally extending portion 862 and a transversely extending portion 864. Each of the clip members 869 has a transversely extending tab 872 which is positioned on the top surface of the transverse portion 864 of angle brace 861. Tie bar 866 is positioned beneath angle brace member 861, with the flange portion 867 of the tie bar abutting the underside of the transverse portion 864 of the angle brace member. The header tank member 874 is then positioned so that the flange portion 880 thereof is disposed against the transverse tabs 872 of the respective clip members 869. In this fashion, the apertures 879 in the flange portion 880 of the header tank member are brought into register with the apertures 873 in the transverse tabs of the clip members 869, apertures 865 in the transverse portion 864 of the angle brace member 861 and apertures 868 in the flange portion 867 of tie bar 866, so that bolt or screw means may be inserted through the aligned apertures so as to secure the assembly together. In this manner, apertures 879 in side wall 876 of the header tank member

874 are brought into alignment with apertures 863 in the longitudinally extending portion 862 of the angle brace member 861, so that screw or bolt means can be passed through the aligned apertures for additional securement of the assembly.

Figure 28 is a sectional plan view of a portion of the Figure 27 heat exchanger assembly, showing the details of construction thereof. Channel elements 851 in the array 850 are stacked with their end section side walls 890, 891 in wall to wall contacting relationship adhesively bonded together by adhesive 893 such as epoxy. The channel element and sections each have a cross-section bonded by flat side walls and by edge walls 854 comprising edge wall portions 854a, 854b extending outwardly from the side walls and convergently with respect to each other, with the outermost ends 895 of the edge wall portions being contiguous and coextensive with respect to one another to form a leak-tight edge wall. In this manner, a first fluid face is formed at an end of the array, having a perimeter defined by edge wall ends of the stacked channel elements and outmost side wall ends 892 of the outermost channel element 853 in the array. The serpentine-shaped sealing member 858 extends along the end section edge walls of the channel element at a side of the stacked array. The sealing member 858 has a bearing surface with a generally corrugated contour of grooves 859 and interposted ridges 860 shaped so that the grooves surround and abut the edge wall of a single channel element of the array with the interposed ridges extending inwardly and abutting the facing edge wall portions of adjacent channel elements. The bearing surface of the sealing member 858 is bonded to the abutted channel element edge walls associated therewith by means of adhesive medium 897. The exterior surface of the sealing member 858 is adhesively bonded to the longitudinally extending second segment 870b of the clip member 869 by means of adhesive medium 898. The side wall of the outermost channel element 853 in the stacked array is adhesively bonded to tie bar 866. As shown, the third end segment 871 of the clip member 869 is deformed contiguously around the transversely outwardly extending flange portion 880 of the header tank member to secure the header tank member in position.

Figure 29 is a sectional elevational view of a portion of the heat exchanger assembly of Figure 27. In the portion of the assembly as shown, the channel element 900 has an end section 901 and edge wall portions 902 having outer ends 903 which form a leak-tight edge wall. The channel element features a secondary surface fin 904 with slatted, louver-type surface distortions 905 thereon. The header tank member 874 has a transversely outwardly extending flange portion 880 at an end of the side wall portion 875. The sealing member 858 has bearing surface with a generally corrugated contour of grooves 859 and interposed ridges 860, with each of the grooves shaped so as to surround and abut the edge wall of a single channel element of the array with the interposed ridges extending inwardly and abutting the facing edge wall portions of adjacent channel elements. The bearing surface of the sealing member 858 is bonded to the abutted channel element edge walls associated therewith by adhesive bonding medium 910. Sealing element 858 suitably has a length as measured parallel to the channel element longitudinal axis of at least 0.2 inch which is substantially greater than the thickness t of the sealing member as measured perpendicular to the channel element longitudinal axis at a lower extremity of the grooves in the bearing surface thereof. The headering arrangement comprises clip member 869 having a transversely extending first segment 870 leak-tightly abutting the outer end 858a of the sealing member 858, a longitudinally extending second segment 906 integrally joined to the transversely extending first segment 870 and adhesively bonded to an exterior surface of the sealing member by adhesive bonding medium 909, and a third end segment 871 integrally joined to the longitudinally extending second segment 906 and deformed contiguously arround the transversely outwardly extending flange portion 880 of the header tank member 874 to secure the header tank member in position. As shown, the clip member second segment 906 is also adhesively bonded to the header tank member enclosure side wall portion 875 by adhesive 908 to further secure the header tank member in position.

Figure 30 is an isometric view of a portion of a heat exchanger assembly employing another type of headering arrangement which may suitably be employed in a heat exchanger according to the present invention. In the portion of the assembly as shown, the heat exchanger core 799 comprises a stacked array of channel elements 800 each having edge wall portions 802 which form a leak-tight edge wall. The header tank member 874 has a transversely outwardly extending flange portion 880 at an end of the side wall portion 875. The sealing member 858 has a bearing surface with a generally corrugated contour of grooves 859 and interposed ridges 860, with each of the grooves shaped so as to ~~surround~~ and abut the edge wall of a single channel element of the array with the interposed ridges extending inwardly and abutting the facing edge wall portions of adjacent channel elements. The bearing surface of the sealing member 858 is suitably bonded to the abutted channel element edge walls associated therewith by an adhesive bonding medium as described hereinabove in connection with Figure 29. Sealing element 858 preferably has a length as measured parallel to the channel element longitudinal axisof at least 0.2 inch which is substantially greater than the thickness of the sealing member as measured perpendicular to the channel element longitudinal axis at a lower extremity of the grooves in the hearing surface thereof. The headering arrangement comprises clip member 869 having a transversely extending first segment 870 leak-tightly abutting the outer end 858a of the sealing member 858, a longitudinally extending second segment 806 integrally joined to the transversely extending first segment 870 which may be adhesively bonded to an exterior surface of the sealing member 858 by any suitable adhesive bonding medium, and a third end segment 871 integrally joined to the longitudinally extending second segment 806 and deformed contiguously around the transversely outwardly extending flange portion 880 of the header tank member 874 to secure the header tank member in position. As shown, a gasket 890 is positioned in a groove in the side wall 875 of the header tank member 874 such that the gasket bears compressively against the upper surface of the clip member first segment 870 to form a leak-tight seal between the heat exchanger core assembly and the header tank member 874. In practice, the gasket may be formed of any suitable material as for example Buna-N or neoprene having a durometer value of 60 to 80.

The heat exchange channel element of this invention as incorporated in automobile radiator exchangers has been extensively tested relative to the prior art stacked channel element heat exchangers disclosed in Kun U. S. Patent No. 3,757,856; Kun U. S. Patent No. 3,810,509; and Kun U. S. Patent No. 3,845,814. Such testing has amply proven the superiority of the channel element and heat exchanger fabricated therefrom according to the present invention relative to the channel elements and heat exchangers of the aforementioned Kun patents, as shown in the ensuing discussion.

Figure 31 is a graph of convective heat transfer effectiveness factor plotted as a function of Reynold's number, for various heat exchanger embodiments of the present invention and for a heat exchanger constructed in accordance with Kun U. S. Patent No. 3,810,509. The data from which the curve shown in Figure 31 were plotted were generated with radiator heat exchanger test samples, as hereinafter described, in the wind tunnel test apparatus shown in Figure 26 and described hereinabove. In a typical test in the wind tunnel apparatus, the inlet air velocity was maintained at 90°F with a 100°F temperature difference between the inlet air and the temperature of the coolant fluid introduced into the radiator at the inlet face of the heat exchanger core assembly. The coolant fluid circulated through the interior passages of channel elements in the radiator samples during the tests was a mixture of 45% ethylene glycol in water; this coolant was circulated through the radiator samples at the rate of 14.5 gallons per minute per foot width of the radiator, the width of the radiator being measured in a plane containing the longitudinal axes of the stacked channel elements, in a direction perpendicular to the channel element longitudinal axes.

Curve A of Figure 31 is based on data for a radiator sample constructed in accordance with the prior art. Each channel element in the radiator sample was fabricated from 0.008 inch thick aluminum in the manner taught in Kun U. S. Patent No. 3,810,509. Each channel element was 1.112 inches wide and the primary surface wall member was provided with eliptical shaped wall-supporting projection portions having an effective diameter, d as defined in the Kun patent of 0.137 inch. The wall-supporting projection portions were provided in a triangular array with an effective spacing D of 0.48 inch between adjacent projections. Each wall-supporting projection portion of the channel element wall member had a height H of 0.043 inch. Secondary surface fins were provided fore and aft on the edge walls of the channel elements, each fin having a fin angle γ of 30°, a slot angle α of 90° and a slat angle β of 45°, all as defined in the Kun patent. Each secondary surface fin was 0.389 inch wide with an individual slat dimension for the louvered surface distortions on the fin of 0.035 inch by 0.327 inch. The radiator heat exchanger constructed from the above-described channel elements had a density of 100 channel elements per foot width of the heat exchanger, with the width of the stacked array being measured in a common plane containing the channel element longitudinal axes, in a direction perpendicular to the channel element longitudinal axes.

The ordinant of the Figure 31 draft is the dimensionless ratio of the Colburn factor j to the

Fanning friction factor f. This ratio is a convective heat transfer effectiveness factor, with a value of 0.5 being the theoretical maximum value. The abscissa of the draft is the Reynold's number, with the Reynold's number being based on the flow of air through the radiator heat exchanger interchannel spaces in a direction normal to the aforementioned common plane containing the longitudinal axes of the stacked channel elements in the radiator's core assembly. As shown by curve A in Figure 29, a radiator fabricated from primary surface heat exchange channel elements, as described hereinabove, which is typical of the teachings of the aforementioned Kun patent, has a j/f value of about 0.225 at a Reynold's number of 600 which decreases to a j/f value of about 0.156 at a Reynold's number of about 4,000.

The heat transfer performance of the prior art radiator constructed in accordance with the teachings of the Kun patent, as reflected in curve A, is to be contrasted with curves B, C, D and E, which represent the heat transfer performance of various radiator heat exchangers constructed in accordance with the present invention.

In the radiators which were tested to yield curve B - E, the heat exchange channel elements in the radiators were fabricated from 0.008 inch thick aluminum. Each channel element was 0.94 inch in width. The channel elements at a configuration generally similar to that shown in Figure 2 - 4 herein, with the following dimensions: H = 0.055 inch, d_1 = 0.020 inch and D = 0.6 inch. The wall surface between adjacent ridge projections at a circular concave contour with a constant radius of curvature, R_1 of 0.792 inch, and the edge wall of the channel element at a convex contour as shown in Figure 4. Each radiator had 88 channel elements per foot width thereof, with the width of the raidator being measured in a common plane containing the longitudinal axes of the channel elements, as measured in a direction perpendicular to the channel element longitudinal axes.

Curve B of Figure 31 is a plot of heat transfer data for a radiator with a core of the type shown in Figure 18, wherein planar secondary surface plate-like members are disposed between adjacent channel elements. Each plate-like member had smooth surfaces no surface distortions thereon. Each plate-like member was fabricated from aluminum of 0.006 inch thickness and had a width of 0.0625 inch. The secondary surface member was secured between the adjacent channel element solely by the compressive forces between the abutting opposed wall projection portions of the respective channel elements. As shown by the graph of Figure 31, this radiator had a j/f value of 0.275 at a Reynold's number of 600 and a value of about 0.220 at a Reynold's number of 4,000. These values represent a 22% increase in heat transfer effectiveness at the Reynold's number value of 600 and a 41% increase in heat transfer effectiveness at the upper value of Reynold's number of 4,000 relative to the performance of the prior art radiator of curve A.

Curve C is a plot of the heat transfer data for a radiator having a core as shown in Figure 16 herein. The plotted data show that this radiator at a j/f value of 0.320 at a Reynold's number of 600 and a value of about 0.232 at a Reynold's number of 4,000. This performance represents a 42% increase at the lower Reynold's number value of 600 and a 49% increase at the upper value of 4,000 relative to the prior art radiator of curve A. Furthermore, based on these data, the radiator of curve C represents a 16% improvement in heat transfer effectiveness factor at the lower Reynold's number value of 600 and a 6% increase at the upper value of 4,000, relative to the radiator of curve B. Apart from such comparison of convective heat transfer efficiency, the radiator of curve B is superior to the radiator of curve C in other respects, as will be shown more fully hereinafter.

Curve D is a plot of the heat transfer data for a radiator comprising channel elements formed similarly to the channel element of Figure 14 herein, with each channel element being provided with a single front longitudinal secondary surface fin and a single rear longitudinal fin. The secondary surface fins each had slatted, slotted louvered surfac distortions in the manner taught by Kun U. S. Patent No. 3,845,814. The front fin had an angle of orientation γ of 30°, while the rear fin had an angle of orientation of 0°. Each fin had a slot angle α of 90° with a slat angle β of 45°. The fins were each 0.324 inch in width with the individual slats having a dimension of 0.25 inch by 0.35 inch. The fin angles γ, α and β referred to above are as defined in the aforementioned Kun patent. These finned channel elements were stacked in the heat exchanger core as shown in Figure 17, with a smooth secondary surface plate-like member being disposed between the adjacent channel elements. This radiator had a j/f value of 0.382 at a Reynold's number of 600 and a j/f value of 0.287 at a Reynold's number of 4,000. This performance represents a 70% increase in the convective heat transfer efficiency factor at the lower Reynold's number value of 600 and an increase of 84% at the upper Reynold's number value of 4,000 relative to the prior art radiator of curve A.

Curve E plots the heat transfer data for radiator constructed in the same manner as the radiator of curve D, but without secondary surface plate-like members disposed between adjacent channel elements in the radiator core. Otherwise, the radiator for curve E was identical in all dimensional respects to the radiator of curve D. as shown, the radiator of curve E had a j/f value of 0.422 at a Reynold's number of 600, and a value of 0.318 at a Reynold's number of 4,000. These end-point values for the particular Reynold's number range considered represent convective heat transfer performance improvement of 88% and 104%, respectively, relative to the prior art radiator of curve A. As shown by the graph of Figure 31, the radiators constructed in accordance with the present invention all provided substantial improvement in convective heat transfer efficiency over the full Reynold's number range considered relative to the prior art radiator (curve A) constructed in accordance with the teachings of Kun U. S. Patent No. 3,810,509.

Based on the respective curves B - E of Figure 31, representing various embodiments of the present invention, it might appear that the use of a secondary surface plate-like member between adjacent channel elements in the radiator core, in the manner shown in Figure 18 herein, would be disadvantageous relative to the provision of a heat exchanger core lacking such form of secondary surface, as for example, in a core of the type shown in Figure 17 herein. In Figure 31, the position of the curves C and E, representing radiators with such secondary surface plate-like members, are seen to be positioned vertically above the corresponding curves B and D, respectively, the latter pair of curves representing radiators provided with such secondary surface plate-like members between the adjacent elements in the heat exchanger core. Despite such fact i.e., that the provision of secondary surface plate-like members between adjacent channel elements in the core of the radiator decreases the convective heat transfer effectiveness of the radiator, it is shown in Figure 32 that the heat transfer material effectiveness of the radiators with secondary surface plate-like members is in fact higher than the heat transfer material effectiveness values for radiators lacking such secondary surface members.

Figures 32 is a graph of heat transfer material effectiveness for the radiators previously described in connection with Figure 31, plotted as a function of gas flow velocity at the face of the radiator. The curve designations B - D in Figure 32 refer to the same radiators described in connection with the correspondingly labeled curves in Figure 31. The ordinate of Figure 32 is the material effectiveness of the radiator, expressed in units BTU/lb. of metal in the radiator core, representing the amount of heat transferred, in BTUs, from the coolant flowing through the interior passages of the channel elements to the external heat transfer medium (air) flowing over the exterior surfaces of the channel elements and secondary surface members, if present. The abscissa of Figure 32 is the face velocity of the air flow through the radiator, measured in units of feet per minute; the face velocity is the gas velocity measured at the forward base of the radiator in the test assembly, as measured in a direction perpendicular to the plane containing the longitudinal axes of the stacked channel elements in the radiator core. As illustrated in Figure 32, the use of secondary surface plate-like members between adjacent channel elements in the radiator, represented by curves B and D, provided significant improvement in the heat transfer capacity per unit weight of metal employed in the radiator as compared to the material effectiveness values for the corresponding heat exchanger lacking such secondary surface plate-like members, represented by curves C and E, respectively. Inasmuch as weight considerations are an important factor in general radiator design, the use of secondary surface plate-like members between adjacent channel elements in the manner previously described imparts a valuable design flexibility in radiators according to the present invention, since the same total heat transfer capacity can be realized in a correspondingly smaller sized radiator than if such secondary surface members are not employed. It will be apparent that the choice of whether or not to employ secondary surface plate-like members between adjacent channel elements in heat exchangers constructed according to the present invention will depend on various considerations including those reflected in Figures 31 and 32 of convective heat transfer effectiveness (pressure drop) and material effectiveness of the heat exchanger in terms of the heat exchange capacity per unit weight of heat transfer surface in the exchanger.

The channel elements of the present invention also afford a substantial advantage relative to the channel elements of the previously mentioned Kun patents with respect to the pressure loadings and differentials which the channel elements can accommodate. This is shown by Figure 33, which is a graph of channel element wall member deflection plotted as a function of internal vacuum pressure and also as a function of internal buckling pressure for a channel element according to the present invention (represented by the curves labeled "M") and a channel element sccording to Kun U. S. Patent No. 3,810,509 (represented by curves labeled "N").

In both the buckling and vacuum pressure tests, from which the data plotted in the graphs of Figure 31 were generated, a single channel element was restrained by two blocks each disposed along a side wall of the channel element against the load-bearing end segments of the wall projection portions thereof. The end blocks were formed of rigid plastic and, when positioned against the side wall projections of the channel element, were retained in position by suitable clamping means. Small holes were provided in the blocks through which deflection probes were inserted to measure deflection of the channel element side wall member at the innermost point on the exterior wall surface. In these tests, the deflection of the blocks was also measured and the values measured were subtracted from the indicated values of deflection of the channel element wall member. Both initially open ends of the channel element were sealed with an epoxy sealant, and a tube was provided at one end section of the channel element in closed gas flow communication with the interior passage of the channel element for feeding of gas into the channel element interior passage or exhaustion gas therefrom. The curves in Figure 33 each represent averaged values for multiple runs of the test procedure.

The curves labeled "N" in the graphs of Figure 31 were based on tests involving channel elements fabricated from aluminum of 0.008 inch thickness in the manner taught Kun U. S. Patent No.3, 810,509. The surface of such channel element was provided with a multiplicity of wall projection portions distributed across the wall member surface, each projection having a circular load-bearing end segment with a diameter of 0.045 inch. The wall surface projections were provided in a triangular array with an effective spacing between projections of 0.48 inch and the height of each wall supporting projection was 0.043 inch. The channel element according to the present invention, which was tested to yield the curves labeled "M" in the graph of Figure 33, was fabricated from aluminum of 0.008 inch thickness and had the dimensional parameters set forth in Table I herein under the heading "Figure 5 Elevational Contour".

In the vacuum pressure deflection test, reflected in the plots on the left-hand side of Figure 33, gas was evacuated from the channel element through the aforementioned conduit in gas flow communication with the interior passage of the channel element and the deflection of the wall member surface between adjacent wall projections was measured at various values of vacuum pressure, measured in units of inches of Hg. As shown by the plot of vacuum pressure deflection, the prior art channel element of curve N relatively large and rapidly increasing levels of deflection with increasing vacuum pressure, while the channel element according to the present invention, by comparison, showed relatively little wall deflection even at high negative pressure level. For example, at a vacuum pressure of -20 inches Hg, the deflection measured for the prior art channel element curve N was about 0.43 mm while the wall deflection of the channel element according to the present invention at the same vacuum pressure level was only 0.04 mm. The deflection of the channel element according to the present invention was thus over 90% lower than the wall deflection of the channel element according to the prior art, at the vacuum pressure level of -20 in. Hg.

The right hand plot in Figure 33 shows deflection of the channel element wall member as a function of positive internal pressure in the channel element interior passage. As shown, the deflection values characteristic of the prior art channel element (curve N) are substantially and increasingly greater than the deflection values for the channel element according to the present invention (curve M). For example, at an internal pressure level of 50 psi, the prior art channel element of curve N exhibited a wall deflection of approximately .37 mm, while the channel element according to the present invention exhibited a deflection of only 0.097 mm, a value 74% lower than deflection level of the prior art channel element. As also shown by the plot, the channel element of the present invention can accommodate increasing internal pressure levels of up to 60 psi without undue or rapidly increasing deflection. At an internal pressure level of 60 psi, the deflection of the wall member according to the present invention is only about .12 mm, a deflection value which is already exceeded by the prior art channel element at an internal pressure of only 20 psi. The various curves in Figure 33 thus clearly show the striking, substantial and unexpected improvement in channel element structural strength and integrity which is achieved by the channel element of the present invention over prior art channel elements.

Although preferred embodiments of the present invention have been described in detail, it will be appreciated that other embodiments are contemplated only with modification of the disclosed features, as being within the scope of the invention. For example, although the disclosure herein has been directed primarily to cross flow heat exchangers employing open-ended channel elements, it will be appreciated that the heat exchange wall member of this invention may suitably be employed in other heat exchanger configurations, such as the plots and fin variety, in various flow modes including cross flow, concurrent flow and counter flow of the heat exchanging fluids.

WHAT IS CLAIMED IS:

1. A heat exchange wall member of thermally conductive material having a multiplicity of wall projection portions distributed across the wall member surface and extending outwardly therefrom with load-bearing end segments at their extremities, whereby said wall member may be supported abuttingly against an adjacent structural member by said load-bearing end segments of said wall projection portions, characterized in that:

said wall projection portions extend elongately on said wall member surface with the load-bearing segments thereof having an aspect ratio (d_2/d_1) of at least 10, wherein d_2= length of the major axis of said wall projection portion load-bearing end segment measured in the base plane of the wall member and d_1 = length of the minor axis of said wall projection portion load-bearing end segment measured in the base plane of the wall member,

said wall projection portions are oriented on said wall member surface with the major axes of said load-bearing end segments of said wall projection portions aligned substantially parallel to one another; and said wall projection portions have a dimensional size and a dimensional relationship therebetween defined by a D dimension of between about 0.2 and 3.0 inch, a H/D ratio of between about 0.05 and 0.5, and a D/d_1 ratio of between about 1.5 and 50, wherein: H equals the maximum height measured perpendicularly from the base plane of the wall member to the innermost point on the wall member surface between adjacent wall surface projections; D equals the spacing between the major axes of load-bearing end segments of adjacent wall projection portions as measured perpendicularly to said major axes in the base plane of the wall member; and the base plane of the wall member is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent.

2. A heat exchange channel element including two spaced-apart wall members of thermally conductive material bounding a fluid flow channel and having a multiplicity of wall projection portions distributed across the wall member surface and extending outwardly therefrom with load-bearing end segments at their extremeties, whereby said channel element may be supported abuttingly against an adjacent structural member by said load-bearing end segments of said wall projection portions, characterized in that:

said wall projection portions extend elongately on said wall member surface with the load-bearing segments thereof having an aspect ratio (d_2/d_1) of at least 10, wherein d_2= length of the major axis of said wall projection portion load-bearing end segment measured in the base plane of the wall member and d_1 = length of the minor axis of said wall projection portion load-bearing end segment measured in the base plane of the wall member;

said wall projection portions are oriented on said wall member surface with the major axes of said load-bearing end segments of said wall projection portions aligned substantially parallel to one another; and

said wall projection portions have a dimensional size and a dimensional relationship therebetween defined by a D dimension of between about 0.2 and 3.0 inch, a H/D ratio of between about 0.05 and 0.5, and a D/d_1 ratio of between about 1.5 and 50, wherein: H equals the maximum height measured perpendicularly from the base plane of the wall member to the innermost point on the wall member surface between adjacent wall surface projections; D equals the spacing between the major axes of load-bearing end segments of adjacent wall projection portions as measured perpendicularly to said major axes in the base plane of the wall member; and the base plane of the wall member is a plane containing the extremities of wall surface projections extending outwardly from the wall member surface to a uniform extent.

3. A heat exchange channel element according to claim 2 wherein said two spaced-apart wall members constitite side walls of the channel element and are spaced apart by edge walls, with said side walls and edge walls each having a thickness of between about 0.003 and 0.25 inch.

4. A heat exchange channel element according to claim 3 wherein said side walls and edge walls are formed of aluminum and have a thickness of between about 0.003 and 0.10 inch.

5. A heat exchange channel element according

to claim 2 which extends longitudinally and has an elongated cross section bound by said two spaced-apart wall members as side walls spaced apart by edge walls, said channel element having a first fluid entrance opening at one end and a first fluid exit opening at the opposite end.

6. A heat exchange channel element according to claim 5 wherein said wall projection portions extend across substantially the full width of the side wall and are oriented with the major axes of said wall projection portion load bearing end segments substantially perpendicular to the longitudinal axis of the channel element.

7. Apparatus according to claim 1 or 2 wherein the wall surface between adjacent wall projection portions is substantially planar.

8. Apparatus according to claim 1 or 2 wherein the wall member surface between adjacent wall projection portions is concavely curved.

9. Apparatus according to claim 1 or 2 wherein the wall surface between adjacent wall projection portions has an elevational contour which is concavely circular.

10. A heat exchanger comprising at least one heat exchange channel element according to claim 2.

11. A heat exchanger comprising a multiplicity

of channel elements according to claim 2 each having an elongated cross section bound by said wall members as side walls spaced apart by edge walls, said channel elements being longitudinally aligned in parallel spaced relation each with a first fluid entrance opening at one end and a first fluid exit opening at the opposite end, and common inlet manifold means and common exit manifold means respectively associated with said first fluid entrance openings and said first fluid exit openings.

12. A heat exchanger according to claim 11 wherein the load-bearing end segments of wall projection portions of said channel elements are shaped and arranged for mating with and abutting against load-bearing end segments of the projection portions of an adjacent channel element side wall, with the wall surface portions between said projection portions thereby forming spaces between adjacent channels through which a second fluid may be flowed in heat exchange with the first fluid.

13. A heat exchanger according to claim 12 comprising secondary surface fins associated with said channel elements.

14. A heat exchanger according to claim 11 wherein said multiplicity of channel elements are disposed in a stacked array with secondary surface plate-like members being disposed between adjacent channel

elements with the load bearing end segments of the wall projection portions of the channel elements being shaped and arranged for mating with and abutting against said secondary surface members, whereby said secondary surface members are maintained in thermal contact with said channel elements along the abutting load-bearing end segments thereof.

15. A heat exchanger according to claim 14 wherein said secondary surface members are substantially planar.

16. A heat exchanger according to claim 14 wherein said secondary surface members have a multiplicity of surface distortions distributed across portions of their surfaces which are not in abutting contact with channel element load-bearing segments.

17. A heat exchanger according to claim 16 wherein said surface distortions of said secondary surface members comprise parallel slats and slotted apertures arranged in a louvered configuration across the width of the secondary surface member.

18. Apparatus according to claim 1 or 2 wherein said aspect ratio (d_2/d_1) is at least 30.

19. Apparatus according ——————————

to claim 1 or 2 wherein said wall projection protions extend outwardly to a uniform extent and have flat load-bearing end segments at their extremities.

20. Apparatus according to claim 1 or 2 wherein: H is between about 0.035 and 0.080 inch; D is between about 0.4 and 1.1 inch: and d_1 is between about 0.01 and 0.05 inch.

21. A heat exchanger including a stacked array of longitudinally extending channel elements each having two spaced-apart wall members of thermally conductive material bounding a fluid flow channel and a multiplicity of wall projection portions formed from each wall member being distributed across the wall member surface and extending outwardly therefrom to a uniform extent with flat load-bearing end segments at their extremities, whereby said channel elements may be supported abuttingly against adjacent structural members said load-bearing end segments of said wall projection portions, characterized in that:

said channel element wall projection portions extend elongately across substantially the full width of said wall member surfaces of said channel elements with the load-bearing segments thereof having an aspect ratio (d_2/d_1) of at least 30, wherein d_2 = length of the major axis of said wall projection portion load-bearing end segment measured in the base plane of the wa..l member and d_1 = length of the minor axis of said wall piojection portion load-bearing end segment measured in the)ase plane of the wall member;

said channel element wall projection portions are o·iented on said wall member surfaces of said channel elements with the major axes of said load-bearing end seg::nts of said wall projection portions aligned substantia .y parallel to one another and substantially perpendicu.:r to the longitudinal axes of said channel elements and said channel element wall projection portions :aving a dimensional size and a dimensional relationshi· therebetween defined by a D dimension of between about 0.2 ıd 3.0 inch, a H/D ratio of between about 0.05 and 0.5, a ; D/d_1 ratio of between about 1.5 and 50, wherein: H equals th maximum height measured perpendicularly from the bas plane of the channel element wall member to the innermos point on the wall member surface between adjacent wall urface projections of the channel element; D equals the s :ing between the major axes of load-bearing end segments o: adjacent wall projection portions of the channel element : measured perpendicularly to said major axes in tl base plane of the channel element member; · d the base plane of the channel element wall memb is a plane containing the load-bearing segments c :he wall surface projections of said wall member.

22. Apparatus according to claim 1 or 2 wherein said wall projection portions are formed from said wall member.

23. Apparatus according to claim 1 or 2 wherein the H/D ratio is between about 0.05 and 0.4.

24. A heat exchanger according to claim 11 wherein said channel elements are disposed in a stacked array with their longitudinal axes lying in a common plane and said stacked array contains at least 40 channel elements per foot width thereof, with the width of said stacked array being measured in said common plane in a direction perpendicular to the channel element longitudinal axes.

25. A heat exchange wall member according to claim 1 wherein said wall projection portions extend uninterruptedly across substantially the full extent of said wall member in the direction of elongation of said wall projection portions.

26. A heat exchanger comprising at least one heat exchange wall member according to claim 1.

27. A heat exchanger according to claim 26 wherein the load-bearing end segments of wall projection portions of said wall member are shaped and arranged for mating with and abutting against load-bearing end segments of the projection portions of an adjacent wall member, with the wall surface portions between said projection

portions thereby forming spaces between adjacent wall members through which a second fluid may be flowed in heat exchange with a first fluid on the other side of said wall member.

28. A heat exchanger according to claim 27 wherein a multiplicity of wall members are disposed in a stacked array with secondary surface plate-like members being disposed between adjacent wall members with the load bearing end segments of the wall projection portions of the wall members being shaped and arranged for mating with and abutting against said secondary surface members, whereby said secondary surface members are maintained in thermal contact with said wall members along the abutting load-bearing end segments thereof.

29. A heat exchanger according to claim 28 wherein said secondary surface members are substantially planar.

30. A heat exchanger according to claim 28 wherein said secondary surface members have a multiplicity of surface distortions distributed across portions of their surfaces which are not in abutting contact with channel element load-bearing segments.

31. A heat exchanger according to claim 30 wherein said surface distortions of said secondary surface members comprise parallel slats and slotted apertures arranged in a louvered configuration across the width of the secondary surface member.

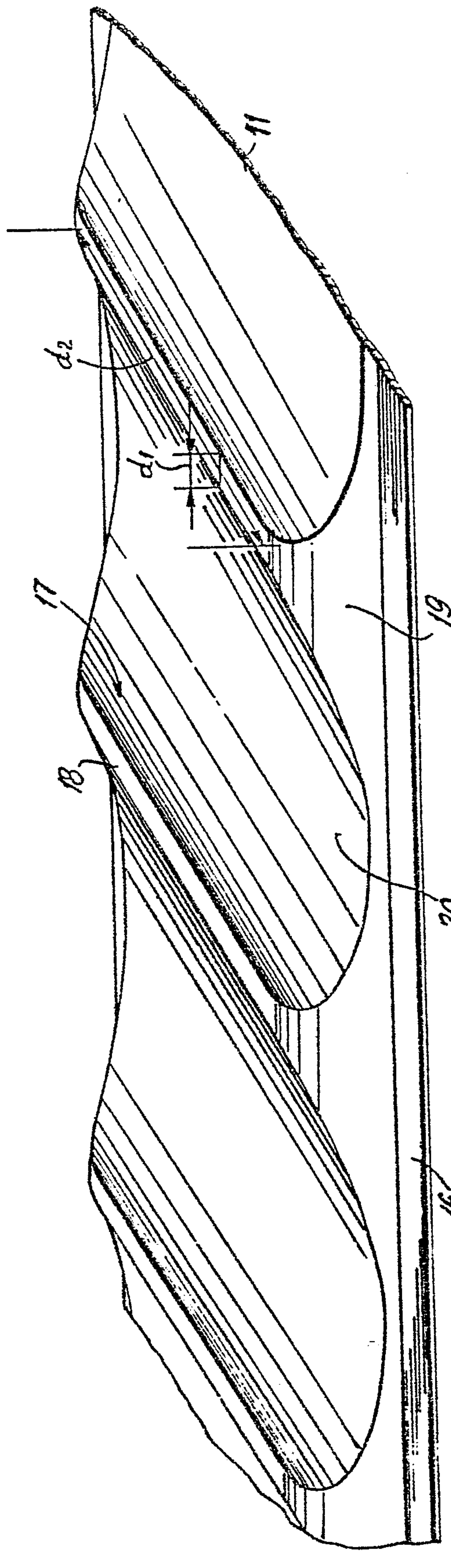

FIG.1

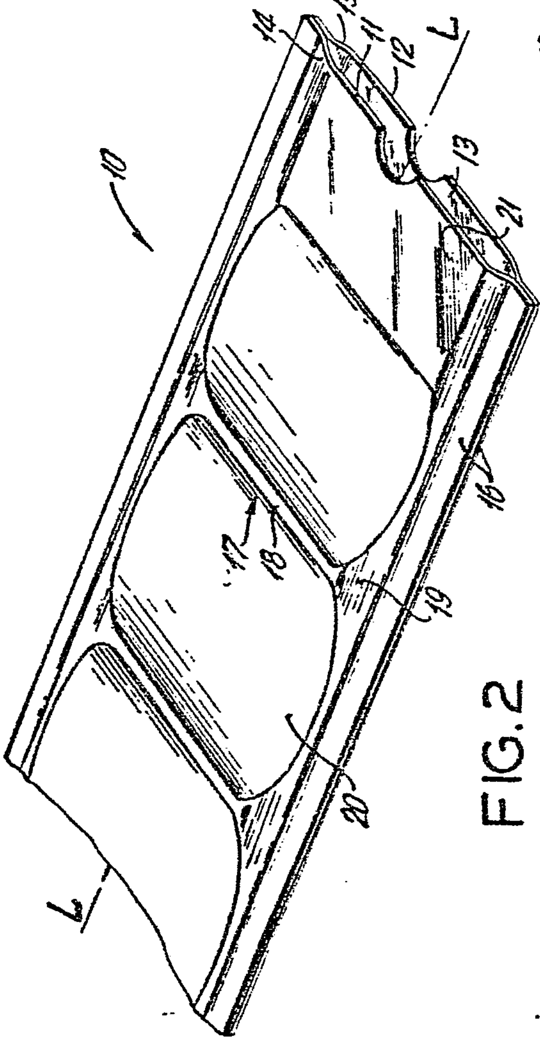

FIG.2

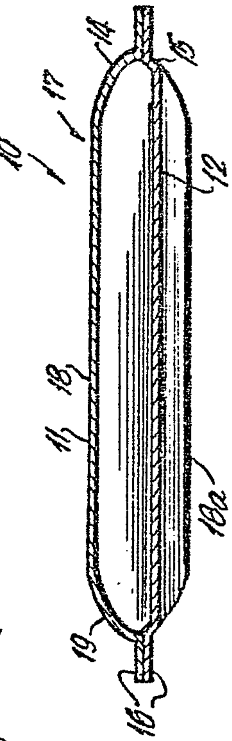

FIG.4

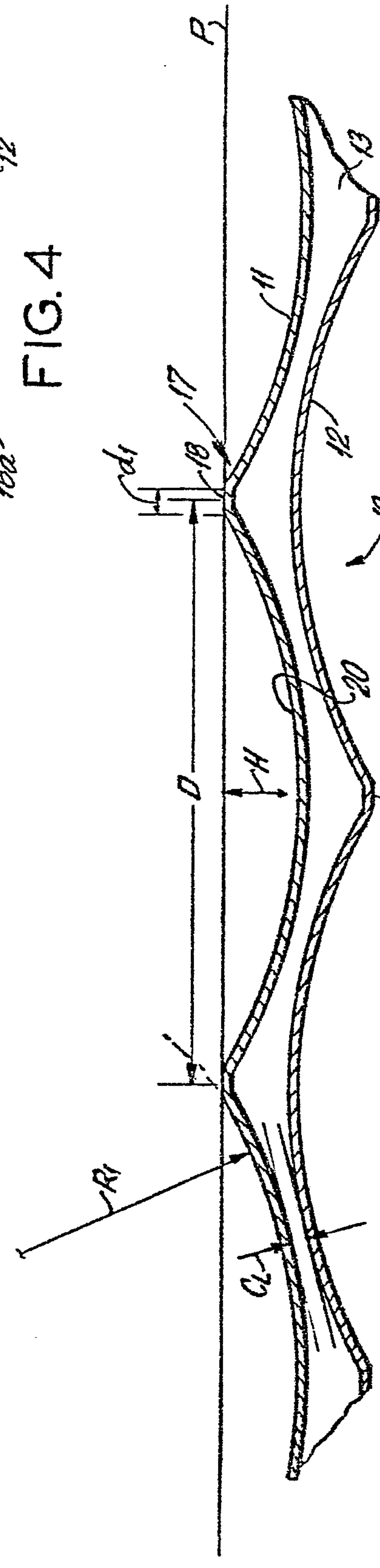

FIG.3

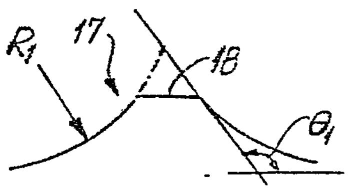

FIG.5

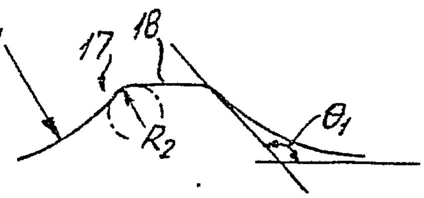

FIG.6

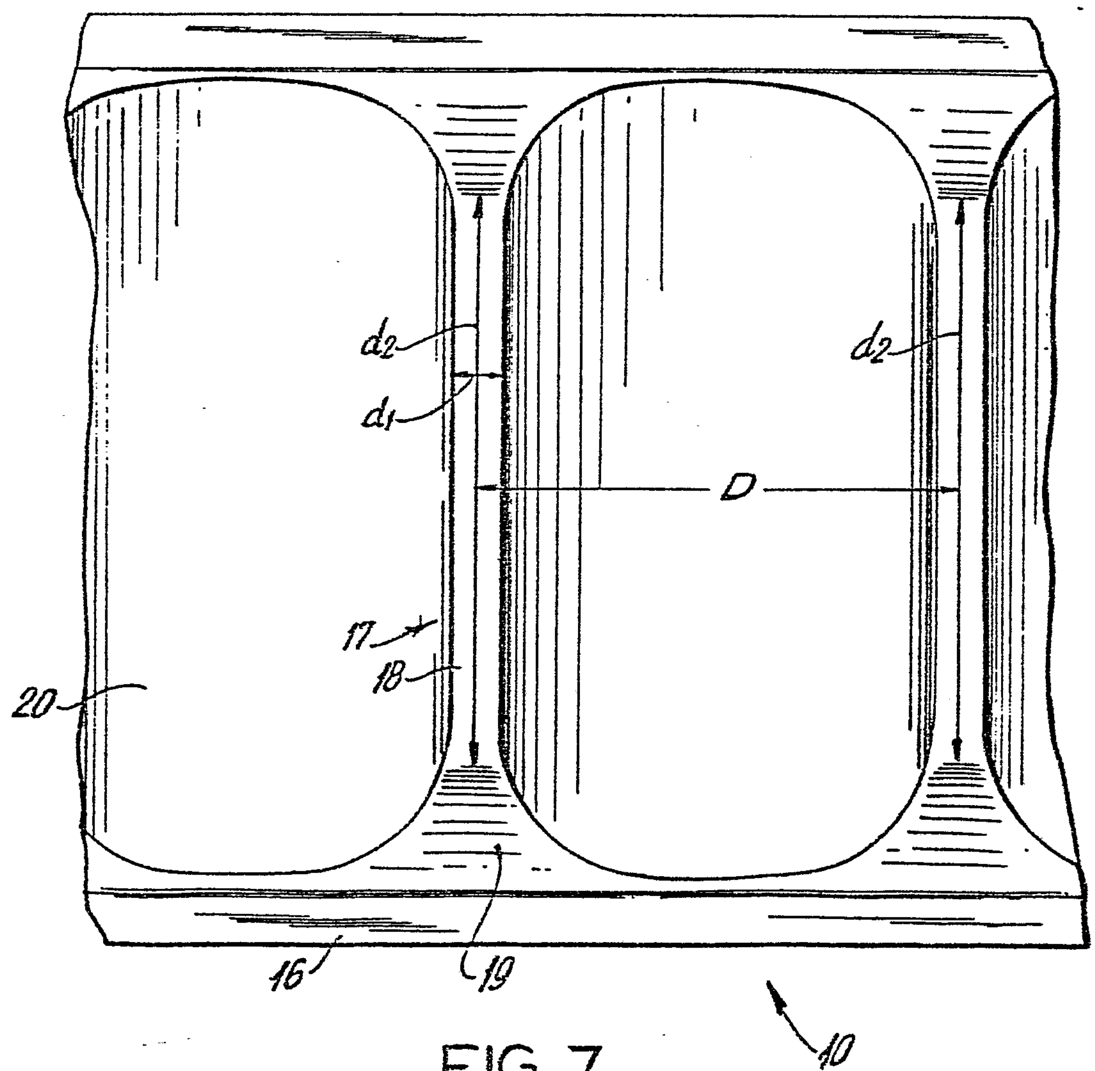

FIG. 7

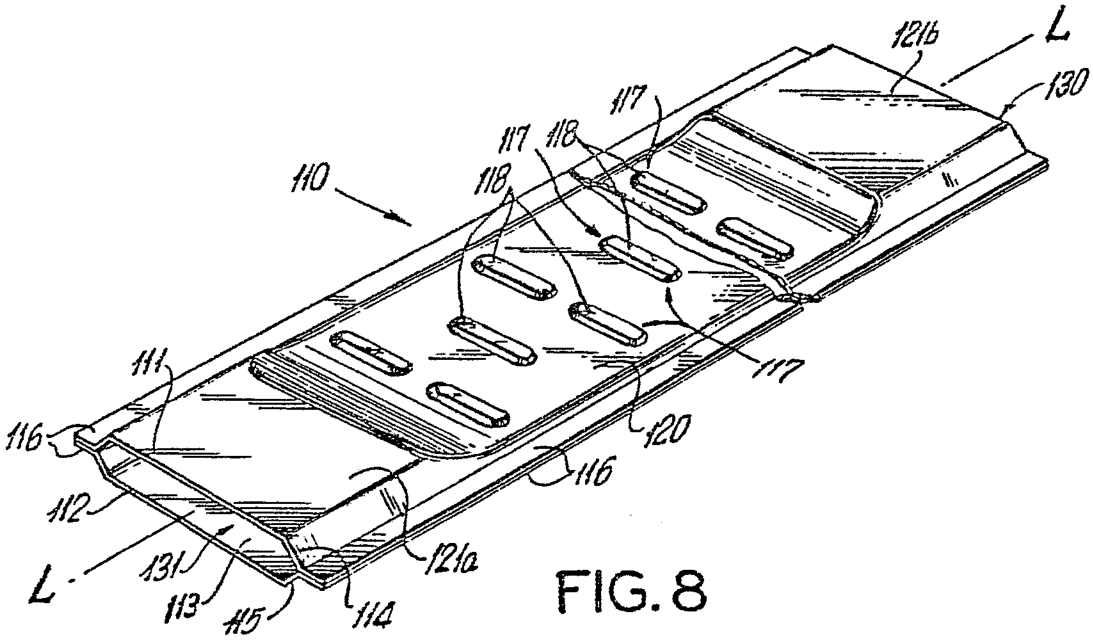
121b
L
130
117
117
118
110
118
117
111
116
120
116
112
131
L
113
115
114
121a

FIG. 8

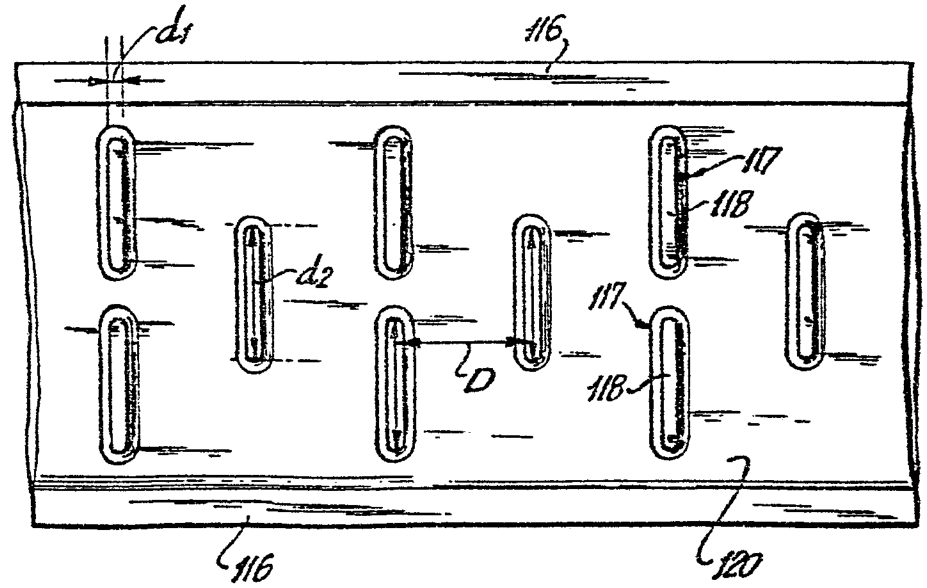
d1
116
117
118
d2
117
D
118
116
120

FIG. 9

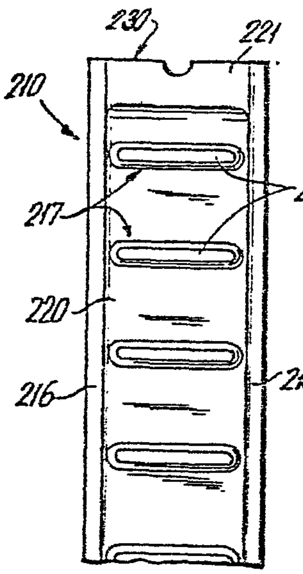

FIG.10

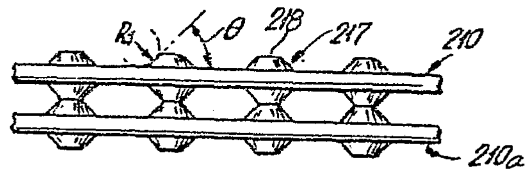

FIG.12

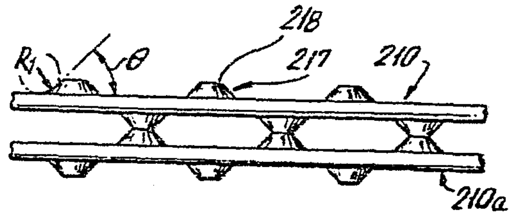

FIG.13

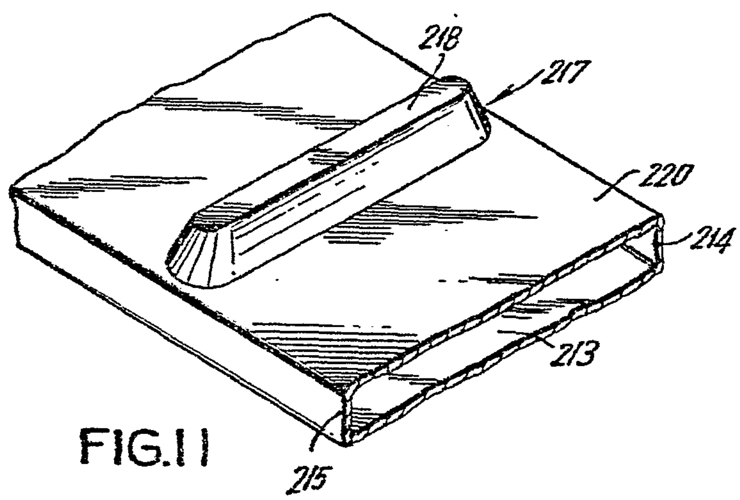

FIG.11

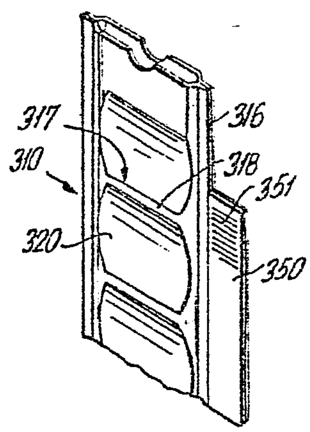

FIG.14

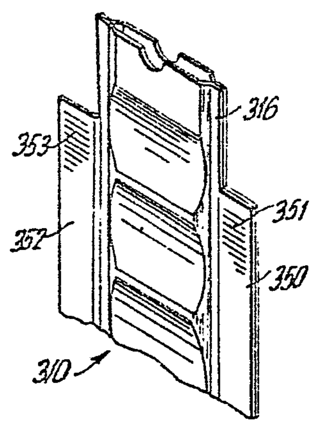

FIG.15

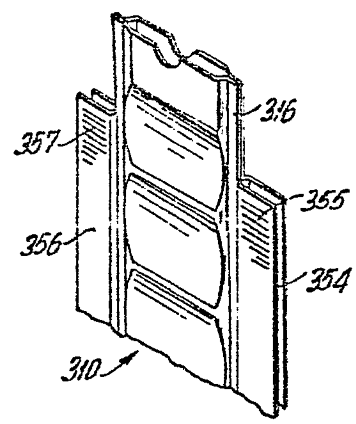

FIG.16

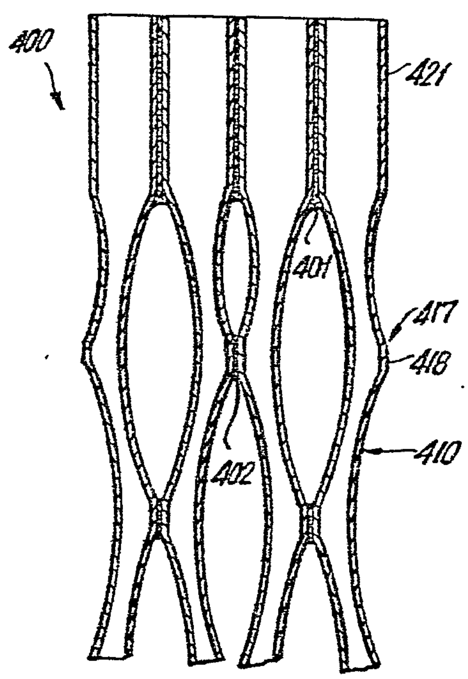

FIG.17

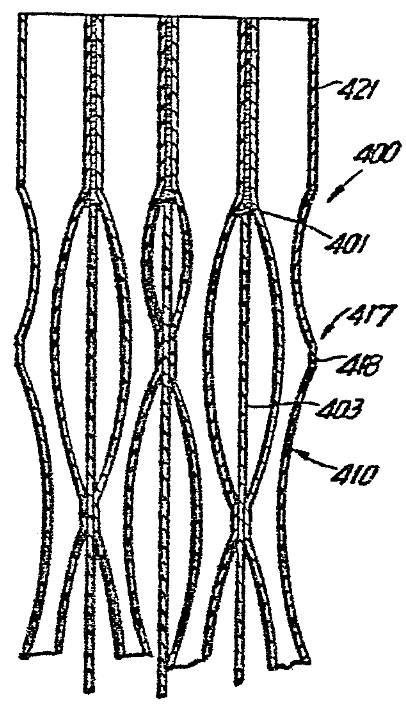

FIG.18

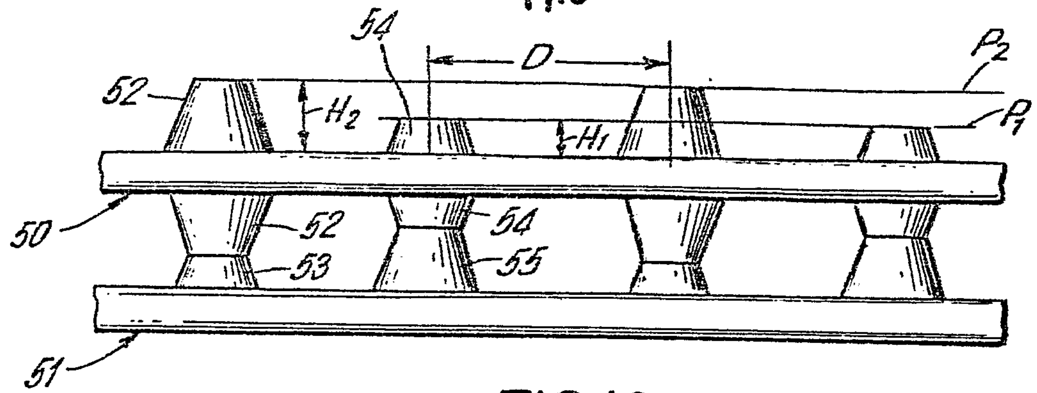

FIG.19

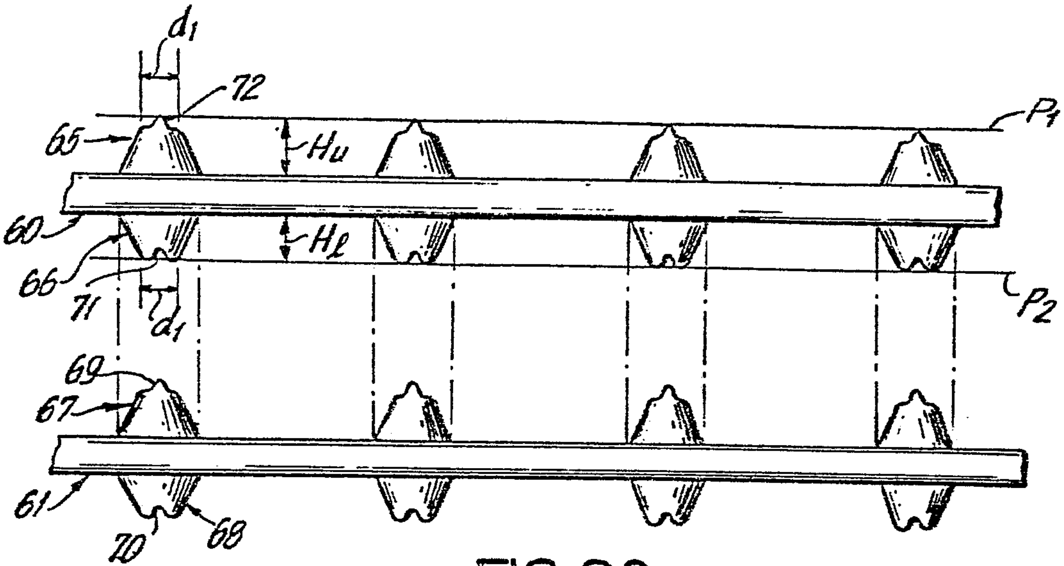

FIG.20

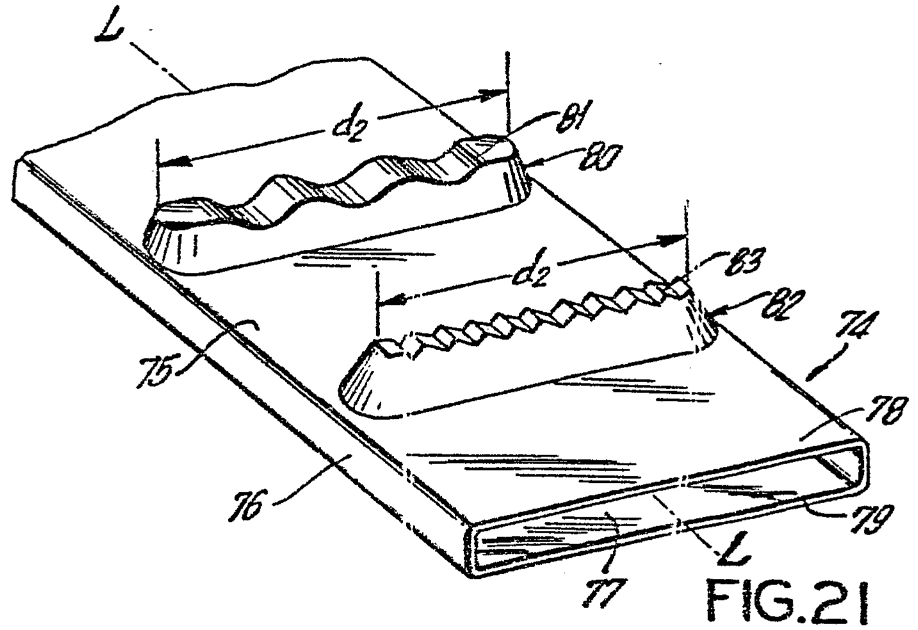

FIG.21

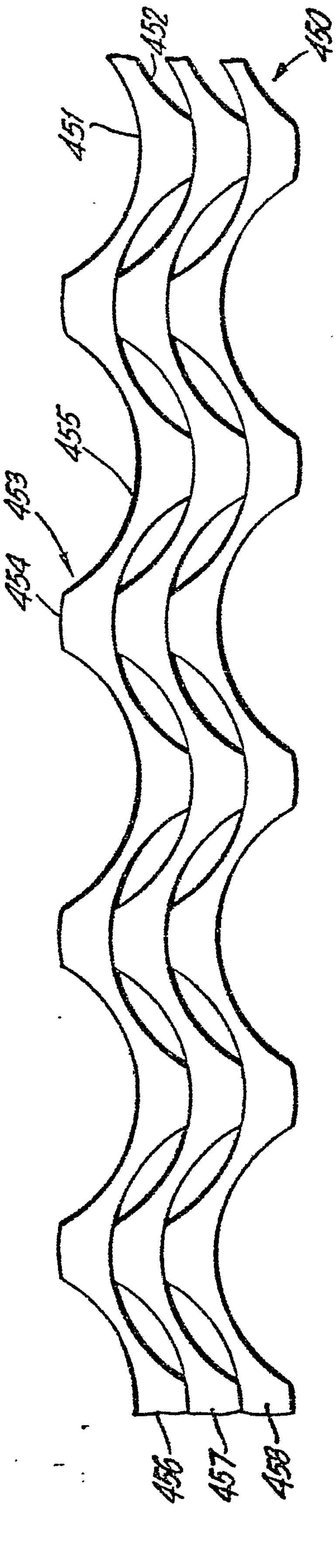

FIG.22

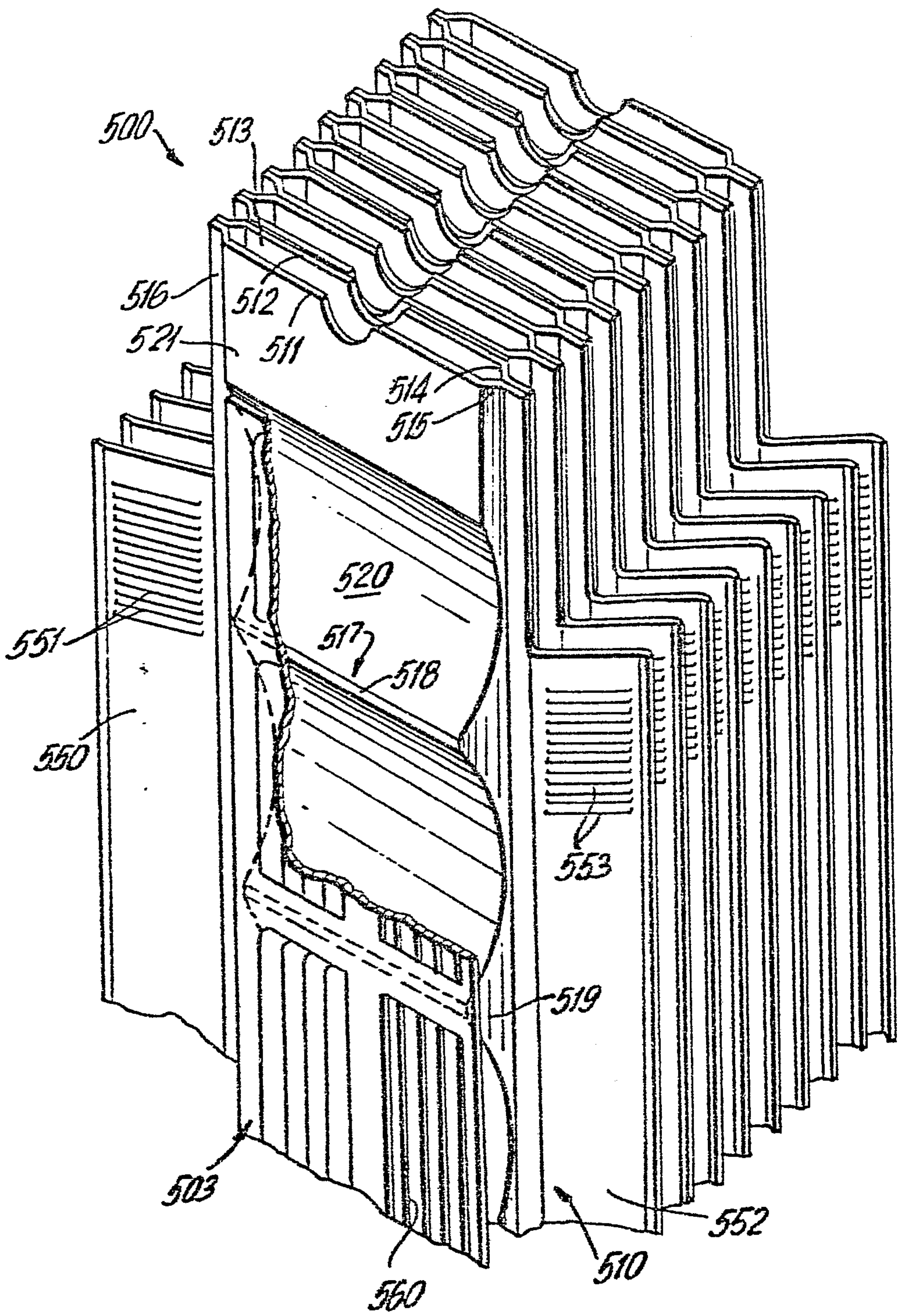
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FIG.23

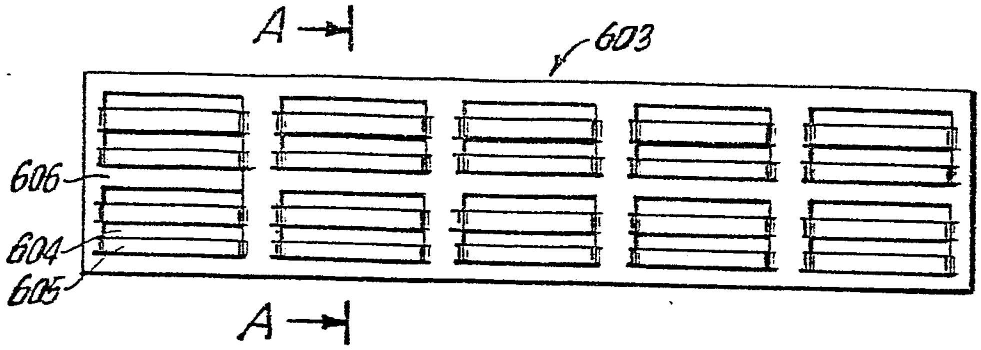

FIG. 24

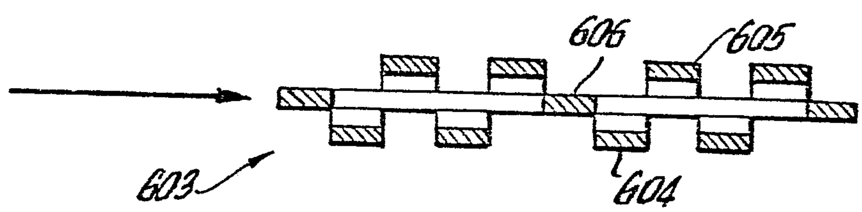

FIG. 25

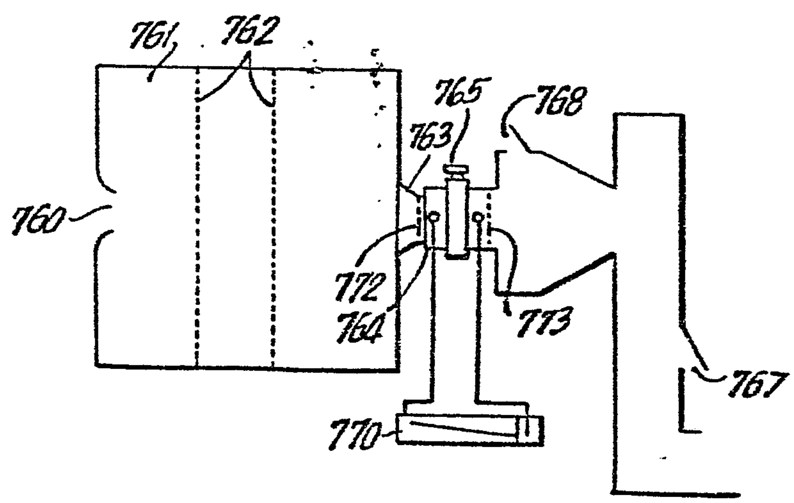

FIG. 26

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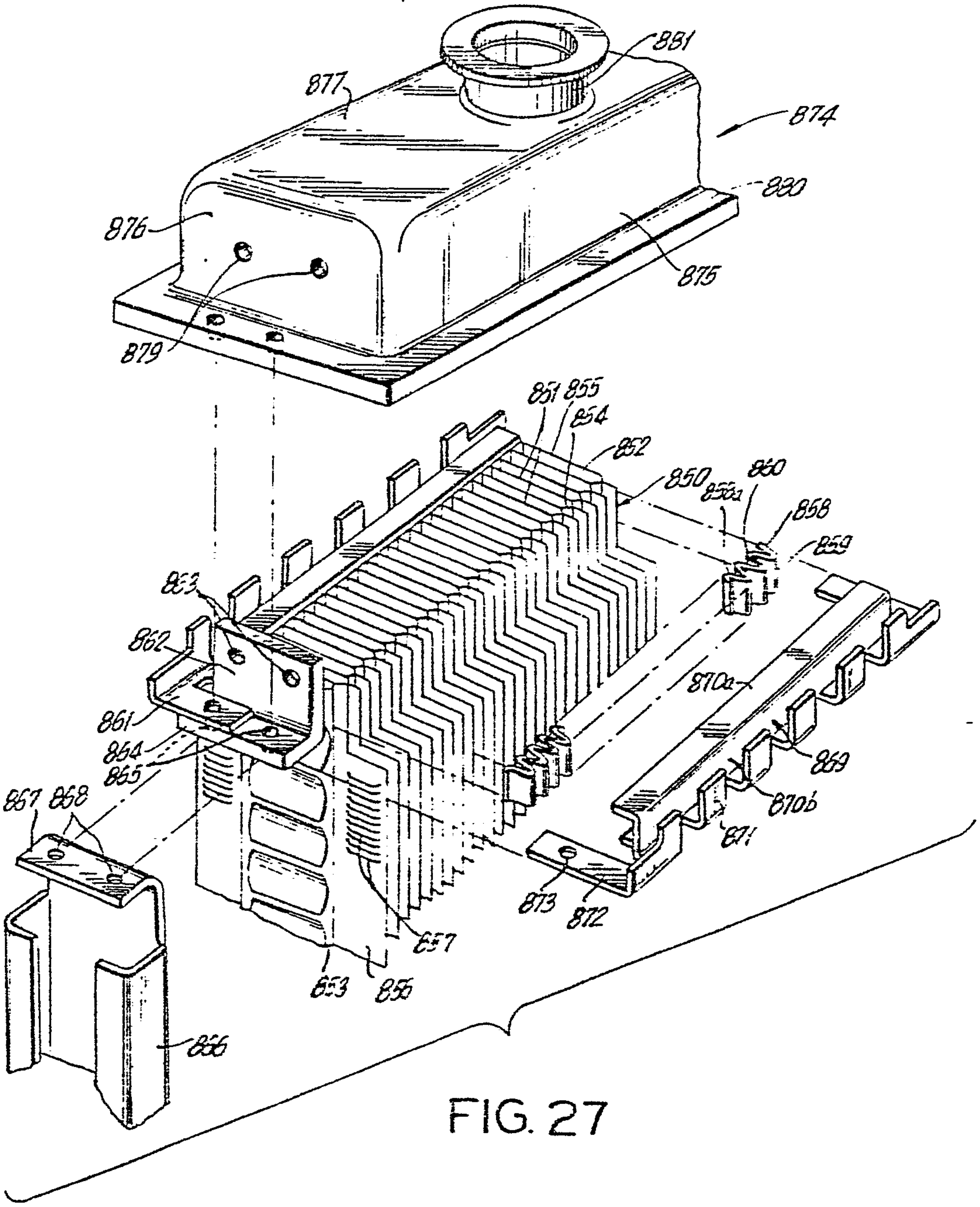

FIG. 27

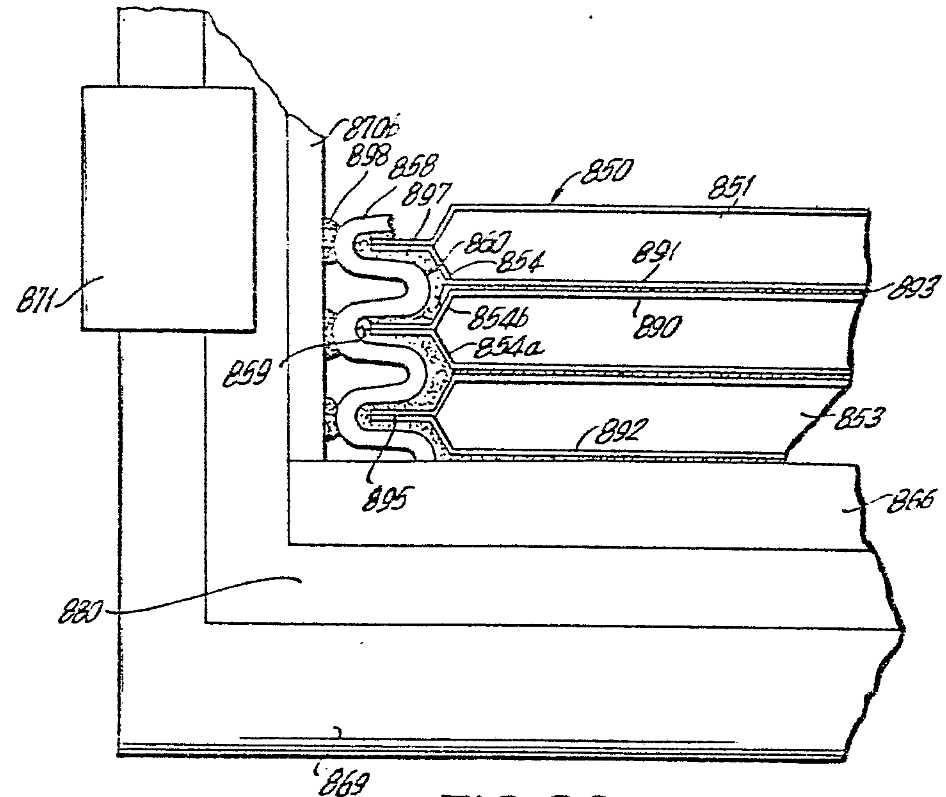
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FIG.28

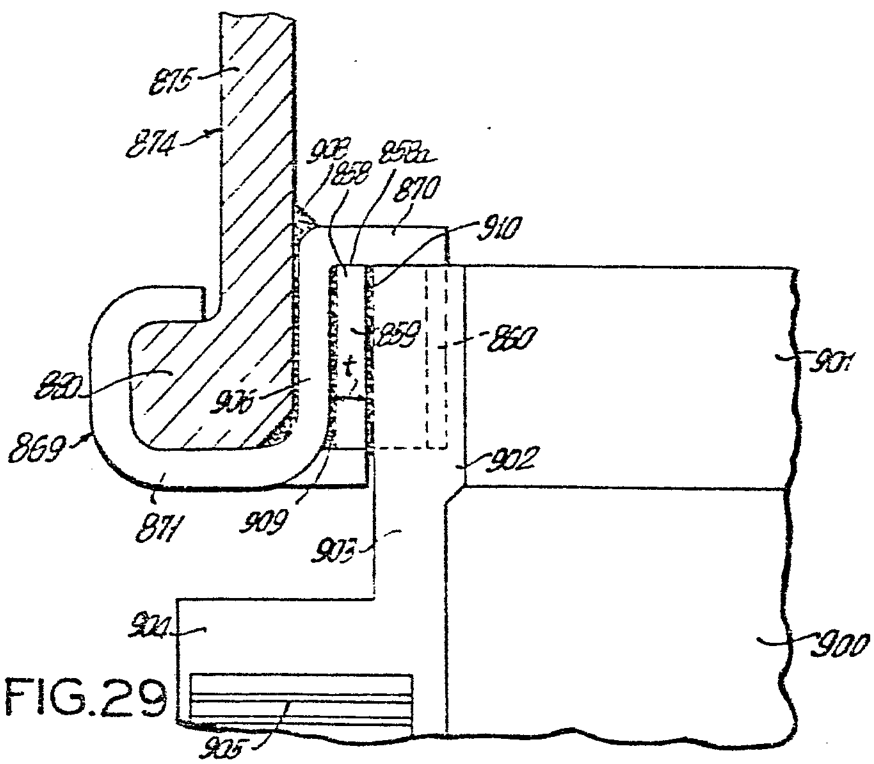
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FIG.29

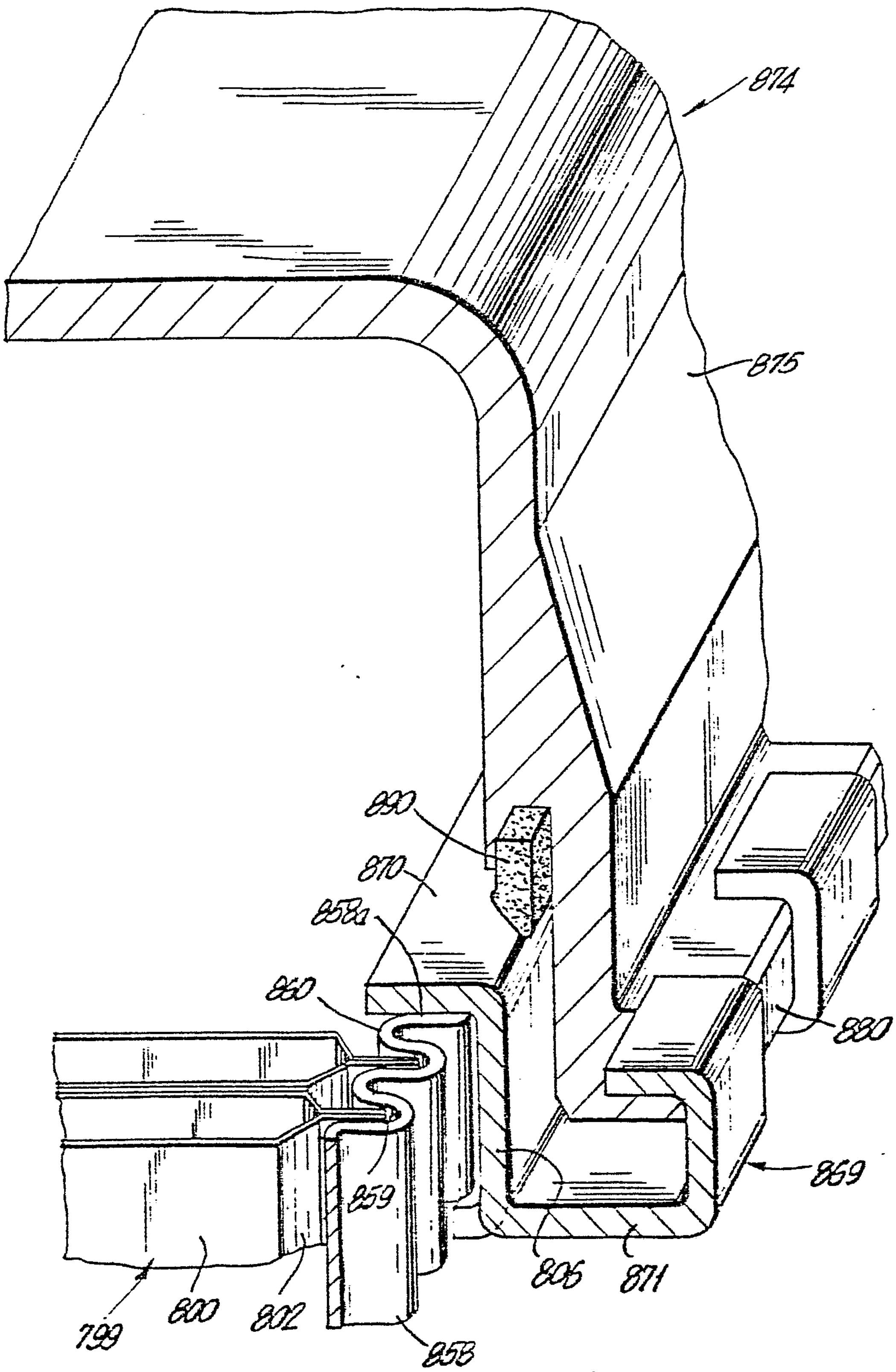

FIG. 30

0014481

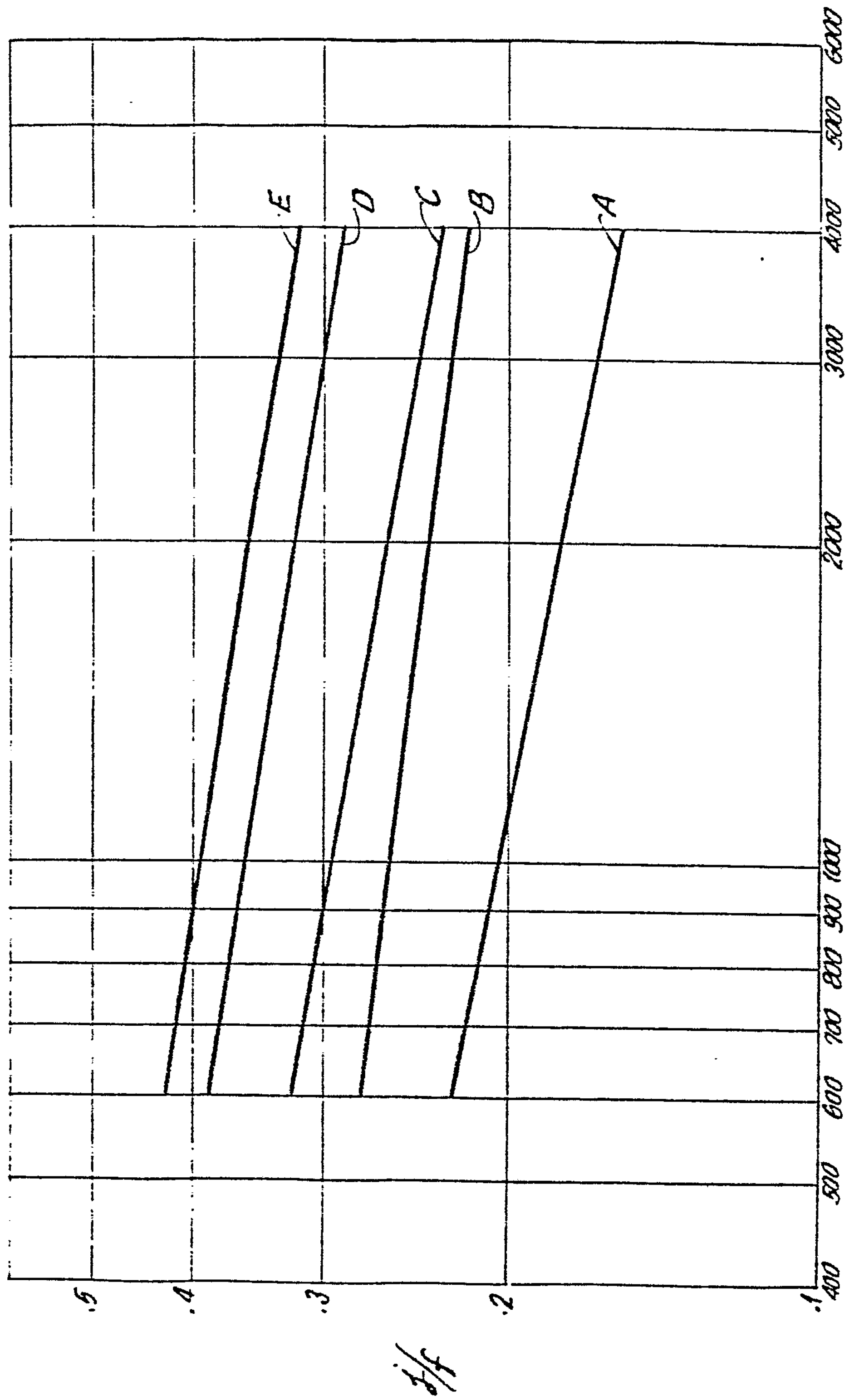

FIG.31

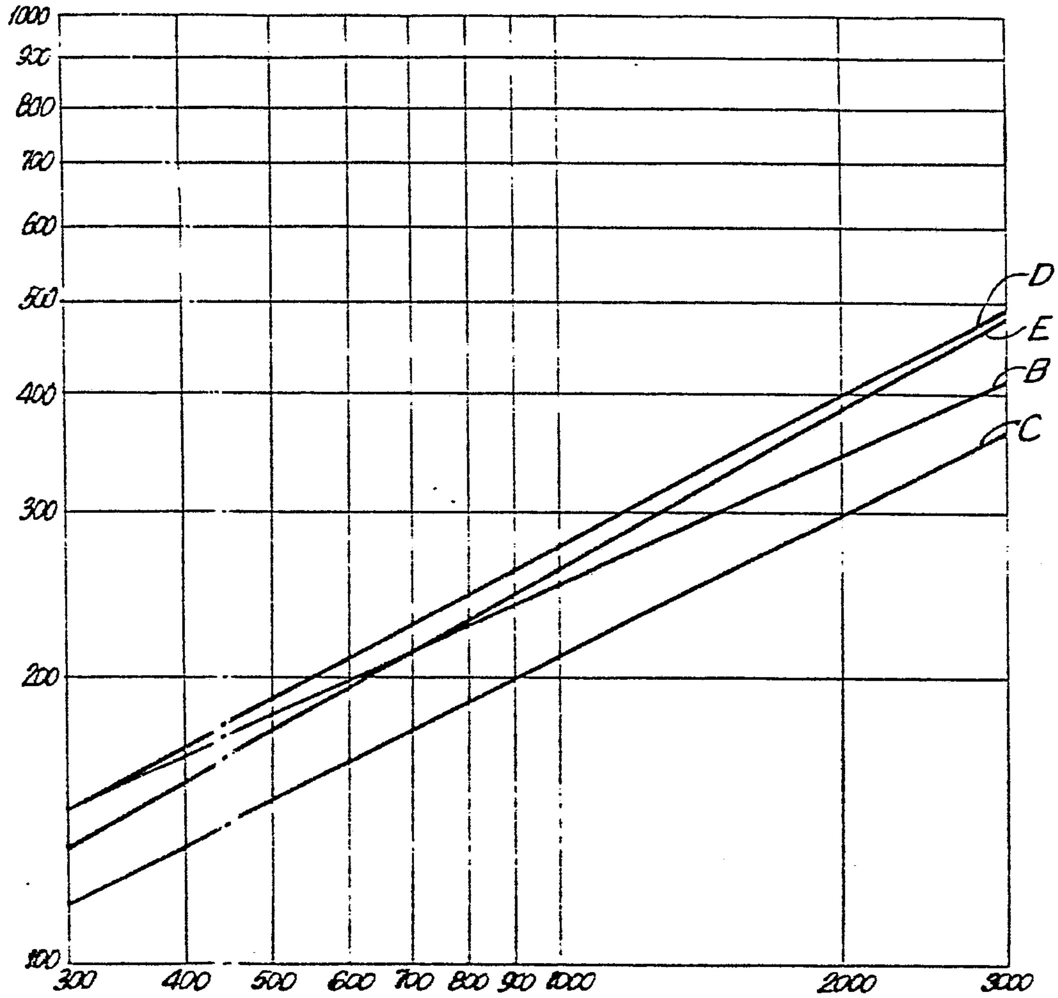
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FIG.32

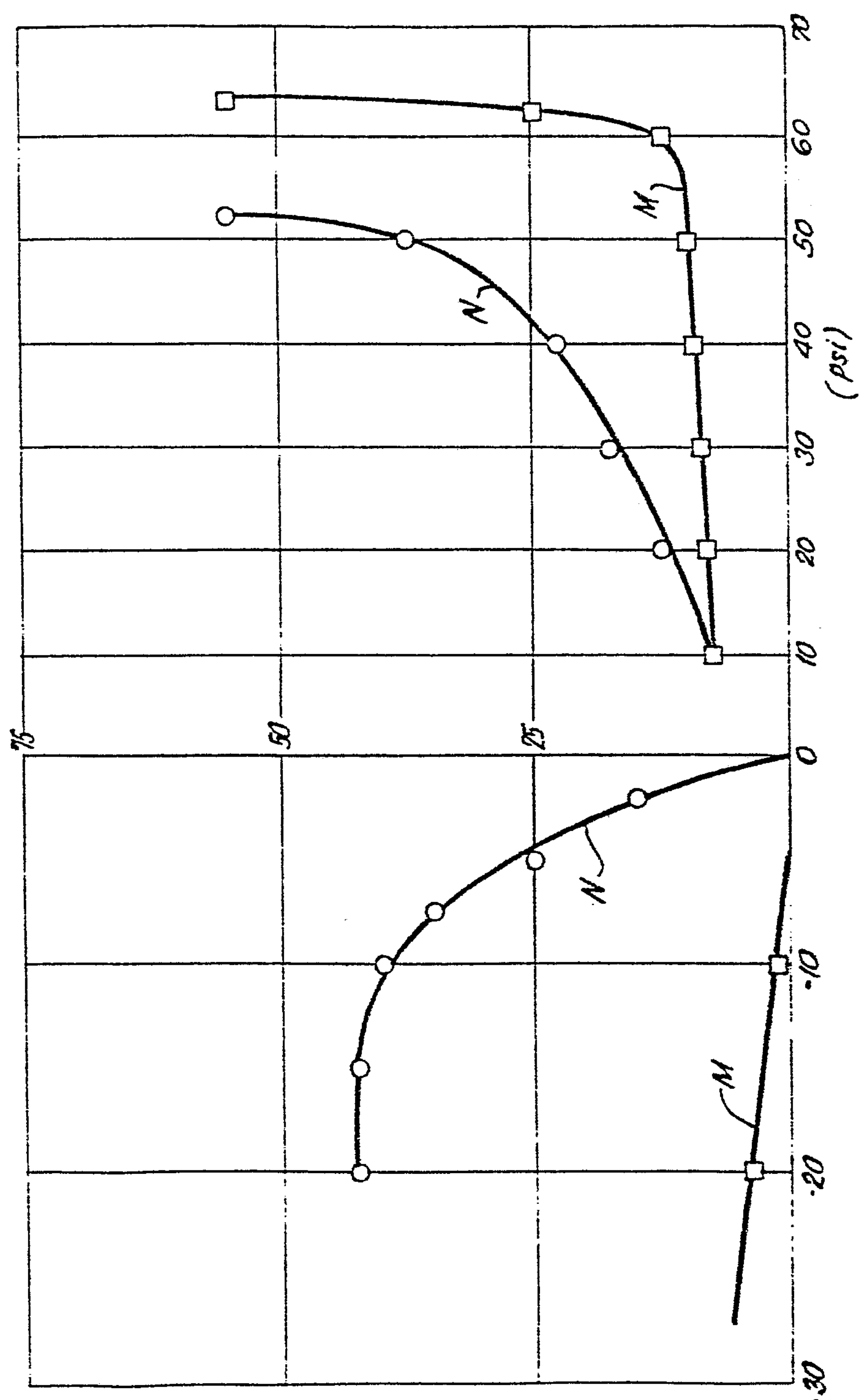

FIG.33