

March 12, 1968

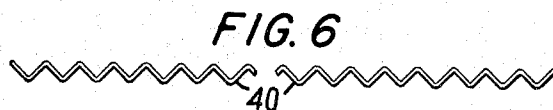
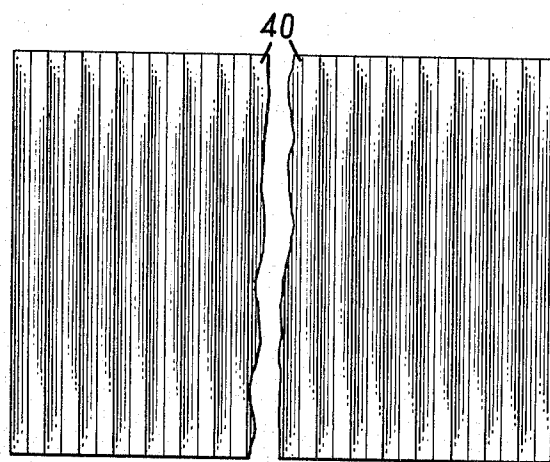
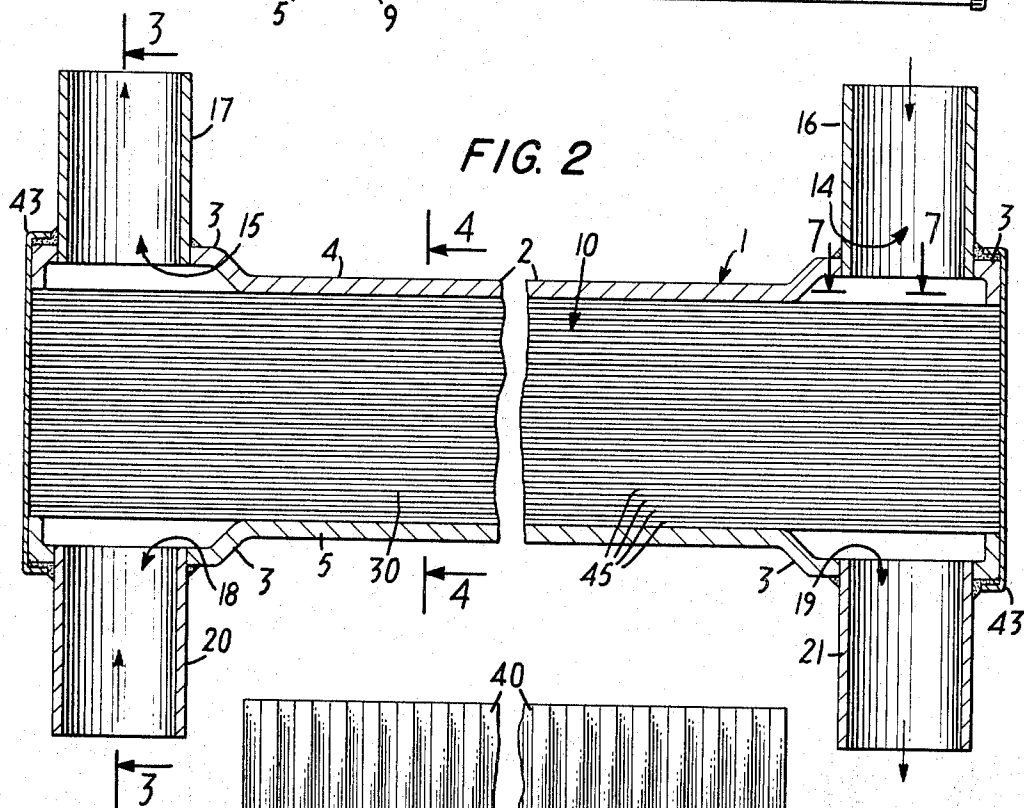
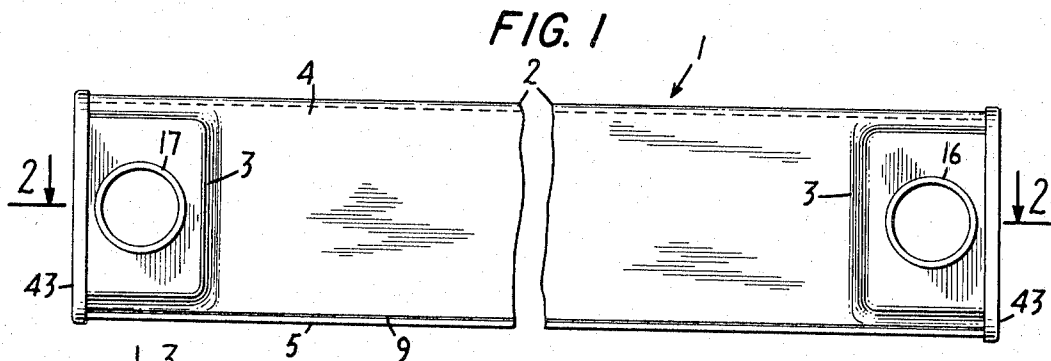
D. B. PALL ETAL

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HEAT EXCHANGER

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FIG. 3A

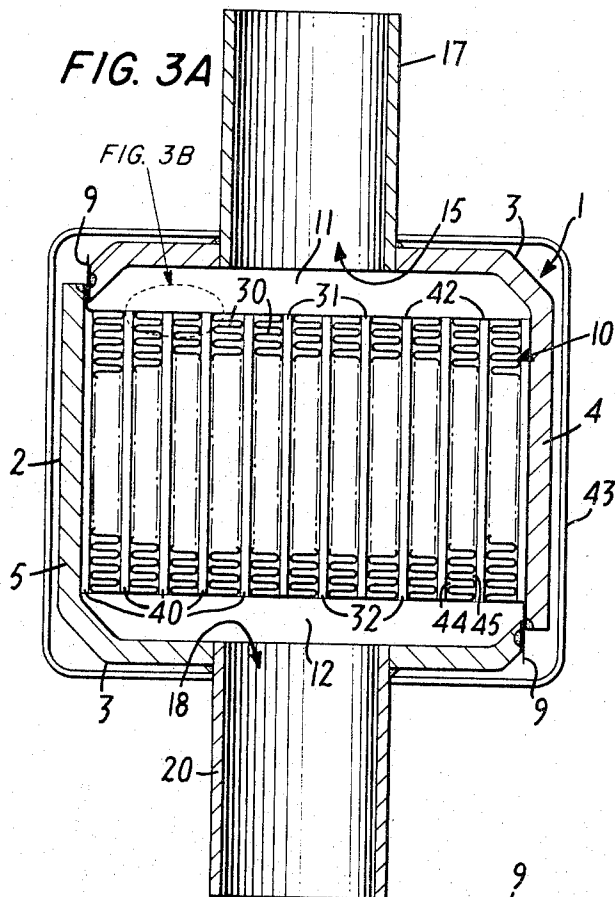


FIG. 3B

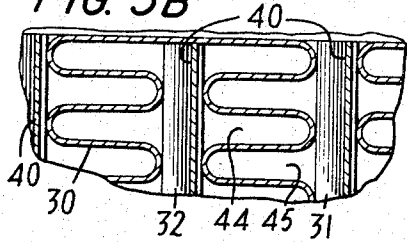


FIG. 8

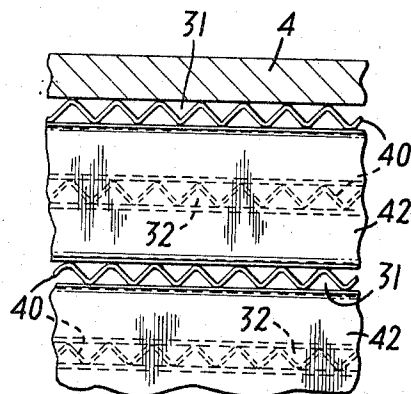
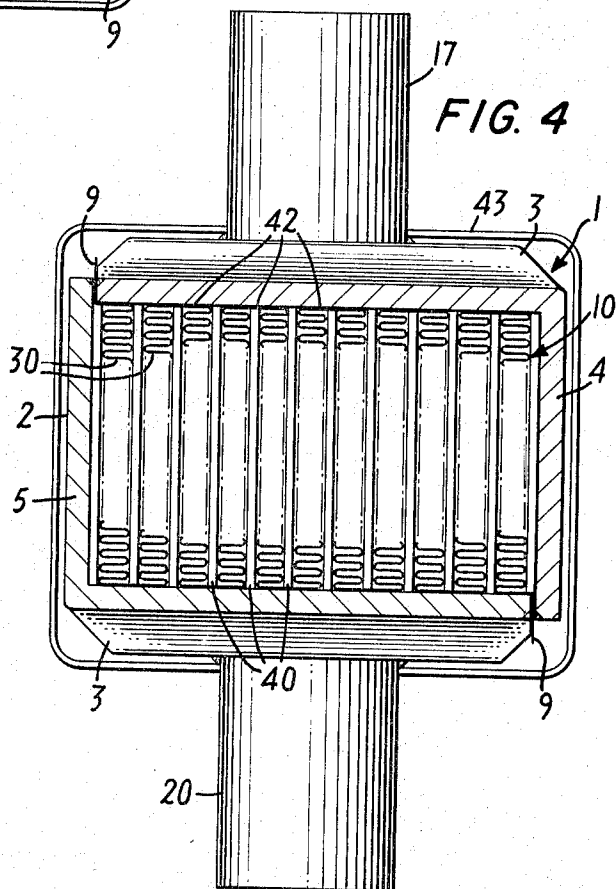


FIG. 7

FIG. 4



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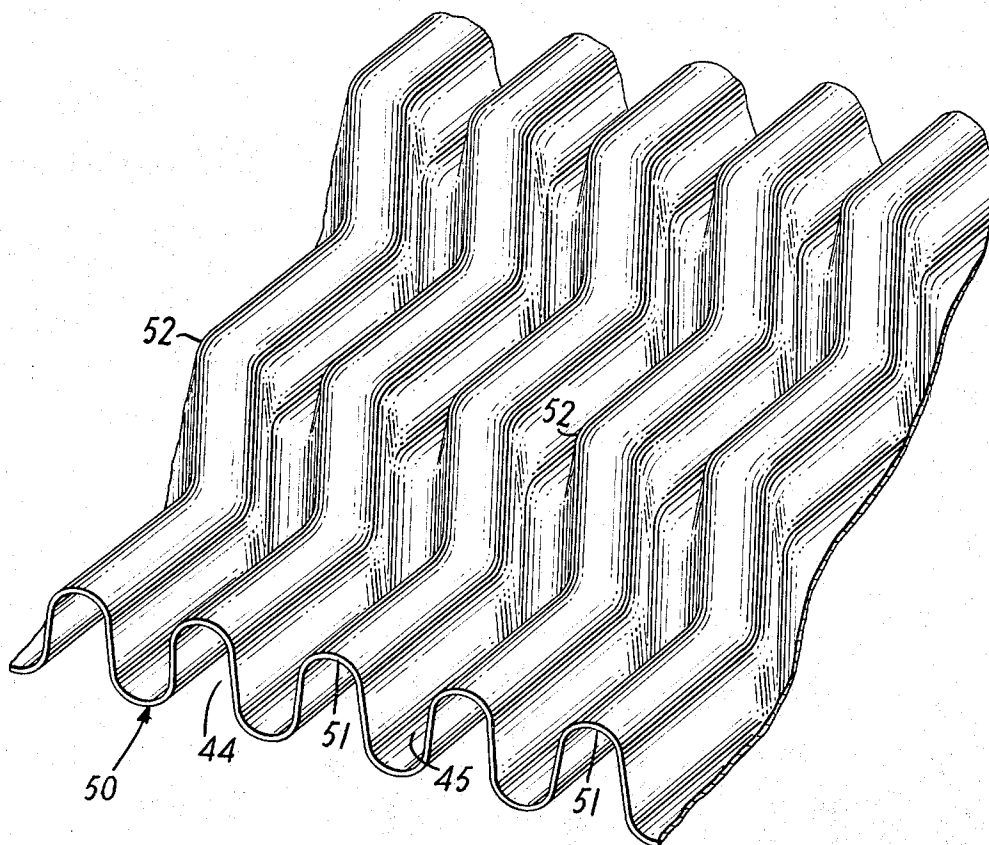
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FIG. 9



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FIG. 12

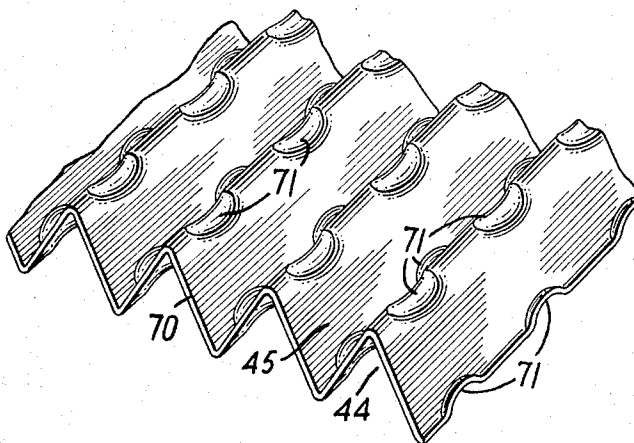


FIG. 10

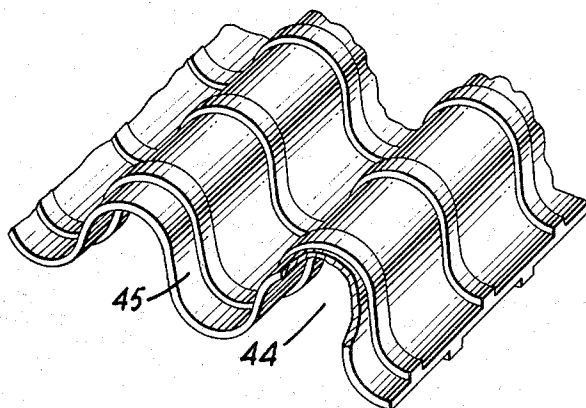
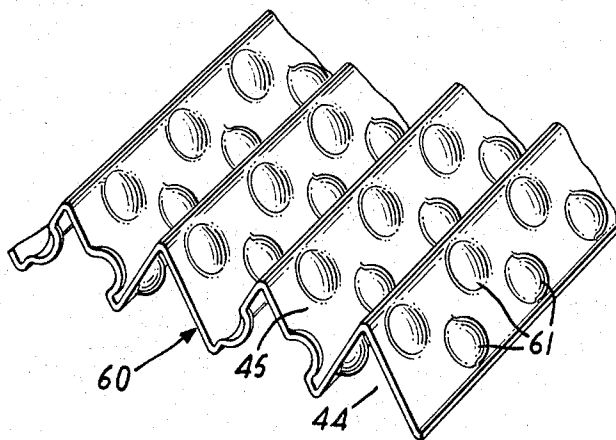


FIG. 11



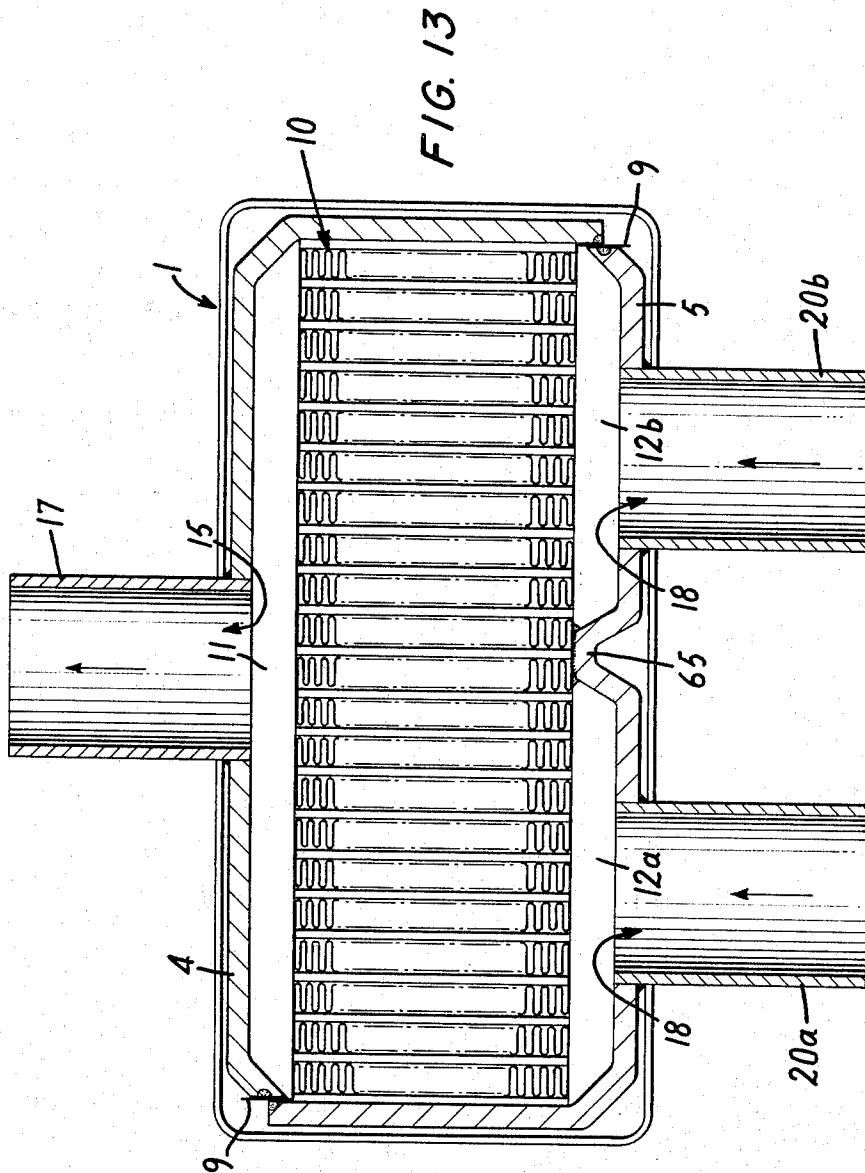
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3,372,743

HEAT EXCHANGER

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Continuation-in-part of application Ser. No. 434,519, Feb. 2, 1965. This application Jan. 25, 1967, Ser. No. 614,521

21 Claims. (Cl. 165—166)

This application is a continuation-in-part of application Ser. No. 434,519, now abandoned.

This invention relates to heat exchangers and more particularly to heat exchangers of the plate type, designed for the exchange of heat between one or more fluids in a manner to permit heat exchange throughout the surface of the plate and without danger of plugging.

The heat exchanger art is very old and highly developed, but despite the many different arrangements of heat exchanger structures that have been provided, heat exchangers are still classifiable only in two large groups: heat exchangers of the tubular type, and heat exchangers of the plate type. This classification is not entirely clear-cut, because it defines only the configuration of the heat exchanger surfaces, i.e. whether they are made up of tubes, or are made up of plates. Even exchangers of the so-called plate type can be made of plates arranged so as to form tubes.

Such a tubular plate-type structure is shown, for instance, in U.S. Patent No. 3,111,982 to Ulbricht, dated Nov. 26, 1963. There, the plates are corrugated and then placed in juxtaposed parallel relationship so that the apices or tips of the corrugations abut, and define tubes formed by the opposed bases of the corrugations, as shown, for instance, in FIGURES 5, 6 and 7 of the patent.

U.S. Patent No. 3,165,152 to Jones, dated Jan. 12, 1965, shows another tubular type made of plates, in this case, corrugated plates with interposed flat separate plates defining a plurality of triangular or three-sided tubes.

In other cases, the plates may be corrugated, and then formed in a tubular configuration, as shown for instance in U.S. Patents No. 2,247,388 to Johnson et al., dated July 1, 1941; No. 2,445,471 to Buckholdt, dated July 20, 1948; and No. 3,120,868 to Ballantine, dated Feb. 11, 1964.

A tubular construction is desirable, in that it permits counterflow heat exchange between the fluids, which can be passed along the inside and the outside of the tubes in opposite directions. Counterflow heat exchange is the most effective technique. However, a tubular exchanger, if made of tubes of a rather small diameter, is subject to a high possibility of plugging. If the tube plugs, it is immediately removed from use. If the material blocking the tube is not removed, a considerable reduction in the efficiency of the device will result. Furthermore, the ends of the tube must be sealed in a leakproof manner in a frame, requiring sealing by welding, brazing or some other technique. Such constructions are prone to develop leaks in use, particularly when the heat exchanger is employed at very high differential pressures between the fluids. The use of plates, as in the Ulbricht and Jones patents, avoids some of the difficulties of tubes, since it is easier to seal a flat continuous plate edge than a multiplicity of tubes, but this construction requires absolute uniformity in positioning of the plates, so that the juxtaposed apices of the corrugations will meet and define the tubes. This construction also has the usual plugging problem of a tubular heat exchanger.

Another problem in a tubular heat exchanger is the control of flow within the tube. It is desirable to keep the flow slow enough to permit effective heat exchange be-

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tween the fluids. It is, however, difficult to form tubes in any other than a straight configuration, and this difficulty is accentuated in a tubular exchanger of the plate type, as shown in the Ulbricht and Jones patents. A convoluted tube also can have an enhanced tendency to plug, because of the convolutions, and again, this is accentuated when the tubes are of small diameter.

The difficulties of controlling flow so as to ensure adequate heat exchange in a heat exchanger of reasonable dimensions have led to the development, particularly for use with gases, of fin-type heat exchangers having an increased surface for the exchange of heat. The finning is made of metal of a high heat conductivity, which is attached to the heat exchanger wall, and disposed in the path of the fluid. One such type of finning is described by Trumpler et al. Transactions of the American Institute of Chemical Engineering, 43, 75 (1947), and is composed of an annular tube packed with an edge-wound helix of copper ribbon solder-bonded to the tube wall. Another type is called the Elliot type, and is composed of a plurality of parallel plates, the space between which is filled with thin stampings. Other types of fin devices are described in the Chemical Engineer's Handbook, Textbook Edition (1950), by Perry.

While the plate type heat exchangers can generally be made more compact than the tubular type for equal heat exchange, they are generally considerably more expensive, thus limiting their use to applications where space and weight are at a premium and cost is a secondary factor.

It is also known to make a heat exchanger comprising a housing divided into two parts by a convoluted plate. However, this type of exchanger contains relatively little surface area for heat transfer compared to a comparably sized unit of the tubular or plate type and not capable of withstanding more than a very small differential pressure between the hot and cold fluids.

In accordance with the invention, a heat exchanger of the convoluted plate type is provided, affording passages for the heat exchanging flow of fluid therethrough which can withstand very high differential pressures, and which can be long enough and wide enough to correspond to the greatest available dimensions within each convolution, with a very high relative surface area for efficient and effective exchange of heat thereacross. The heat exchanger is easily fabricated to ensure a leakproof seal of the heat exchanger wall in the housing, and the characteristics of the fluid passages are such that plugging is virtually impossible.

The heat exchanger in accordance with the invention comprises a housing, a plate disposed in the housing in a manner to divide the housing into two chambers and separate the fluids between which heat is to be exchanged, and openings in the housing for inflow and outflow of the fluids into each chamber, the plate being formed in a plurality of convolutions arranged in juxtaposed spaced-apart relationship within the housing. Each convolution additionally is corrugated, as will presently be seen. A plurality of separators are disposed between the convolutions, and hold the convolutions in spaced-apart relationship. The convolutions are arranged to define passages for flow of fluid across the surface of the heat exchanger plate, and the separators are arranged to hold the convolutions apart, the separators, convolutions and corrugations together defining a plurality of passages therebetween which are interconnected at a plurality of points along their length so as collectively to form a passage extending overall substantially the length and width of each convolution. For optimum surface area, the convolutions are arranged to extend substantially the length and width of the chambers in the housing in each direction, and the

overall passages are of equal dimensions, with a close spacing of the convolutions to provide a plurality of narrow passages therebetween.

The convoluted, corrugated heat exchanger plate thus has high area for heat transfer, and the corrugations and separators define passages for flow of fluid across the surface of the heat exchanger plate. This ensures an effective heat exchange between the fluids along the length of the heat exchanger plate.

The convolutions can be substantially parallel, and generally this is preferred, since this type is easier to fabricate. However, they can also be spaced to form a plurality of V-shaped passages, narrower at the top than at the bottom, and they can also be arranged to fit in any kind of irregular volume, according to space requirements, or to afford any kind of spacing according to flow requirements, and fluid consistency. They can, for instance, be arranged in a fan shape, to afford heat exchange between a more viscous fluid or a slurry on the outside of the fan, and a mobile fluid on the inside.

The heat exchanger plate additionally is corrugated, so as to provide an even greater surface area within each convolution. The plate can also be corrugated so as to provide a wider corrugation passage on one side of the plate than on the other, to accommodate different fluid flow rates, fluid viscosities, or acceptable pressure drops.

The insensitivity to plugging is obtained by providing the fluid interconnections between adjacent corrugations in the same convolution, or between adjacent convolutions. Thus, if a flow passage in one corrugation is plugged at a point along its length, fluid can still flow down that corrugation to the interconnection immediately upstream of the point of plugging, through the interconnection to an adjacent corrugation, in the adjacent convolution to the first interconnection downstream of the point of plugging, through this interconnection and back into the original corrugation. Thus, only the portion of the plugged corrugation between the two interconnections is lost as useful heat transfer surface area. By contrast, in a tubular heat exchanger, whether of the tubular or plate type, the entire length of a tube is lost if the tube is plugged at any one point.

The fluid interconnections are preferably provided by the separators. Alternatively, they may be provided merely by leaving a space between adjacent convolutions, or by flattening or otherwise deforming the corrugations at intervals.

The separators may be disposed between the convolutions on both sides of the heat exchange plate. If desired, the separators may be omitted on the high pressure side of the heat exchange plate.

If the separator is corrugated, the corrugations provide flow interconnections between adjacent corrugations, which paths provide the insensitivity to plugging. If the separator is flat, it may be perforated at periodic intervals, or the corrugated heat exchange plate may be deformed at intervals, to provide flow interconnection between adjacent corrugations.

Besides providing flow interconnections, the separators on the low pressure side support the corrugated heat exchange plate against differential pressure. Thus, it is not necessary to ensure that the apices of opposing corrugations line up. Any degree of misalignment is acceptable since opposing corrugations bear on the separator, rather than on each other.

The construction as heretofore described normally is adequate for effective heat exchange. The corrugations on the plate and separators, since they proceed in opposite directions, ensure turbulence of the fluid within the passages. If it be desired to increase turbulence further, the plate or separator or both can be provided with additional surface irregularities, in the form, for example, of dimples, waffles, ridges, reverse corrugations and the like. These will further obstruct flow in the desired direction,

and lead to a turbulent swirling motion which is most desirable for effective heat exchange.

In addition, if the separator is brazed at its points of contact to the heat exchange plate, or other means are used to maintain the separators and the corrugated plate in intimate contact, the separators will act as fins, increasing the effective heat transfer area.

Since the device of the invention generally leads to approximately rectangularly shaped structures which thus require a rectangular housing, and such a housing is generally weak in its ability to withstand internal pressure, several techniques have been developed as part of the invention to overcome this drawback. One approach is to encase the housing in a cylindrical tube within which the higher pressure fluid is connected. Another is to braze, weld, sinter or otherwise fasten together the housing and all corrugations and separators at their points of contact, thus providing a honeycomb-like structure which has great strength under internal pressure. Of course, the housing can be made of a sufficient thickness of a sufficiently strong material, or a thin housing can be reinforced externally by techniques well known in the art, to withstand the internal pressure.

The device of the invention can be formed of any material which is high in heat conductivity. Metals have the desired rigidity and structural strength, in addition to affording good heat exchange, and accordingly are the preferred construction materials. Any of the metals commonly used in heat exchangers can be employed, for instance, iron, steel, aluminum, tin, titanium alloys, nickel and nickel alloys, zinc, cadmium, silver, copper alloys, nickel-chromium alloys, such as Nichrome and Monel, and magnesium. In some cases, synthetic plastic or resinous materials would be preferred because of their inertness to the fluids with which the exchanger will be used. Plastic materials which are satisfactory include polytetrafluoroethylene, polytrifluorochloroethylene, polypropylene, polyethylene, polycarbonate resins, polyvinyl chloride, polystyrene, polyester resins, synthetic rubbers such as butadiene-styrene, butadiene-acrylonitrile, and butadiene-styrene-acrylonitrile copolymers, cellulose derivatives such as cellulose acetate, cellulose acetate propionate and cellulose butyrate, polyamides, such as nylon, and urea-formaldehyde, melamine-formaldehyde and phenol-formaldehyde resins.

In many cases, the convoluted structure can be formed by molding a synthetic resinous material or casting the metal. Usually, however, it will be found preferable to form a sheet or plate of the resinous material or metal, corrugate it, and then fold it in the desired convoluted configuration. Next, one inserts the separators, which can be made of the same or of a different material, between the convolutions, and then attaches the assembly in the housing in a manner to ensure a leakproof seal between the ends of the plate and the housing. One embodiment of the attachment is shown in FIGURES 1 to 7. The separators should be attached to the plate or the housing for rigidity and strength, but this is not essential, and in any case the ends of the separators need not be attached to the housing in a leakproof manner, since they serve only to support the corrugated convolutions of the heat exchanger plate and in appropriate cases provide the fluid interconnections between convolutions.

The attachment of the plate to the housing is readily effected by coating the ends of the plate with a braze alloy and then brazing the assembly to the housing. Welding and soldering are also effective techniques, and sintering can also be employed in many cases. If the separators are brazed or soldered or welded to the heat exchanger plate, strength is improved, and the separator will then function in part as a fin, converting the device into a plate exchanger of the fin type. Plastics can be heat-solvent-softened and fused, or bonded to adhesives.

To facilitate attachment of the plate assembly in the housing, separate end plates may be utilized. After the

convoluted plate and the separators are assembled to the housing, the assembly is attached to flat end plates in a leakproof seal.

The porting and ducting of the housing to afford inflow and outflow of the fluids between which heat is to be exchanged can be effected in the conventional manner to fit standard pipes. Illustrations of how this can be done will be found in the drawings.

The heat exchanger plate and separator assembly can be readily adapted for use in connection with multiple fluids on either both sides of the heat exchanger plate, or only on one side thereof, by forming the housing with appropriate ducting, and sealing the plate to the housing at a number of points. Such a construction is also suitable for multiple passes of the same fluid through the heat exchanger. The construction of such an assembly will be described in greater detail below.

Preferred embodiments of the invention are shown in the drawings, in which:

FIGURE 1 is a top plan view of a heat exchanger in accordance with the invention;

FIGURE 2 is a longitudinal section of the heat exchanger of FIGURE 1, taken along the lines 2—2 and looking in the direction of the arrows;

FIGURE 3a is a cross-sectional view of the heat exchanger of FIGURE 1, taken along the lines 3—3 of FIGURE 2, and looking in the direction of the arrows;

FIGURE 3b is an enlarged view of portion 3b of FIGURE 3a;

FIGURE 4 is another cross-sectional view of the heat exchanger of FIGURE 1, taken along the lines 4—4 of FIGURE 2, and looking in the direction of the arrows;

FIGURE 5 is a top view of a separator of the heat exchanger of FIGURE 1;

FIGURE 6 is a side view of the separator of FIGURE 5;

FIGURE 7 is a partial view of the heat exchanger of FIGURE 1 showing the separator of FIGURE 5, taken along the lines 7—7 of FIGURE 2 and looking in the direction of the arrows;

FIGURE 8 is a side view of another form of separator for use in the heat exchanger of FIGURE 1;

FIGURE 9 is a perspective view of another form of convoluted cross-corrugated heat exchanger plate in accordance with the invention;

FIGURE 10 is a perspective view of a third form of heat exchanger plate in accordance with the invention;

FIGURE 11 is a perspective view of another form of heat exchanger plate in accordance with the invention;

FIGURE 12 is a perspective view of another form of heat exchanger plate in accordance with the invention; and

FIGURE 13 is a view in cross-section similar to that of FIGURE 3A of a heat exchanger of this invention adapted for use with multiple fluids (or multiple passes of the same fluid) through the heat exchanger.

The heat exchanger of FIGURES 1 to 7 comprises a housing 1, composed of a rectangular tube 2, having raised portions 3 at the ends. The housing is formed in two L-shaped pieces 4 and 5, with the ends 9 of the convoluted heat exchanger plate 10 held firmly between them, and welded together in a leakproof seal. Thus, the heat exchanger plate 10 effectively divides the housing into two separate fluid-tight chambers 11 and 12.

The chamber 11 of the housing is provided with inlet and outlet openings 14 and 15, respectively, into which are fitted the pipe connections 16 and 17 for conveyance of a first fluid into and out from the housing.

The chamber 12 is provided with corresponding inlet and outlet openings 18 and 19, respectively, for entry and exit of a second fluid to be passed through the heat exchanger. Pipe connections for this fluid are provided at 20 and 21, respectively.

The heat exchanger plate 10 is formed into a series of eleven convolutions, each extending across the width of

the housing 1 as best seen in FIGURE 4. As is best seen in FIGURE 3A, the eleven convolutions 30 of the plate are parallel to each other, and spaced from each other and from the housing so as to define a total of twelve narrow passages to facilitate entry of fluid therebetween. Six of the passages 31 are in communication with chamber 11 and the other six passages 32 are in communication with chamber 12. The convolutions are held in a fixed spaced-apart relationship by the separator plates 40, which are snugly fitted in these passages.

Each convolution of the heat exchanger plate 10 is formed of a plurality of hill-and-dale corrugations extending perpendicularly to the convolutions, greatly increasing the surface area available for heat exchange thereacross. The separator plates also are corrugated, with the direction of the corrugations at right angles to the corrugations of the heat exchanger plate. The corrugations of the separator plate are of a depth equal to the width of the passages 31, 32, at their narrowest point, between the apices of the plate corrugations, so that the apices of the separator plate corrugations serve as supports for the convolutions. The apices of the separator plate are brazed to the apices of the corrugations of the heat exchanger plate, for improved strength and rigidity. Because of this metal-to-metal bond, the separator plates also serve as fins in the device, further increasing the surface area available for heat exchange.

As best seen in FIGURES 3A and 3B, a single heat exchanger plate will serve, and is in fact preferable in the device of the invention. In fabricating the device, the heat exchanger plate is folded in a plurality of corrugations and the convolution then formed by bending sections of the corrugated plate in a U-shape at the prescribed ends of each convolution. The flat portions 42 at the top of each convolution are either non-corrugated at the time of fabrication, or represent corrugations that have been pressed out, to form the top of the convolutions. The separator plates are then placed in the spaces between the convolutions. If both the separator plates and the heat exchanger plates are coated with a brazing composition, this entire assembly can then be brazed, fixing the separator plates in position and forming a rigid structure. The two ends 9 of the heat exchanger plate can then be fitted between the housing portions 4 and 5, and welded thereto. The pipe connections 16, 17, 20 and 21 are welded in place in housing halves 4 and 5, respectively, either before or after the assembly of the housing halves to the plate. To complete the exchanger, end caps 43 are brazed to the ends of the assembly using a sufficient amount of braze material to close off the end of each corrugation and convolution, thus providing a leakproof seal.

The structure shown in FIGURES 1 to 7 is made of stainless steel, but obviously other metals or synthetic resinous materials could be used.

In operation, a first fluid is passed through inlet pipe 16 into chamber 14, into passages 31, then into the spaces 44 between the corrugations, whence it flows in heat-exchanging relationship along the convoluted and corrugated surface of the heat exchanger plate 10, emerging from the spaces 44 into passages 31 and then chamber 15 and outlet pipe 17. A second fluid hotter or colder than the first is passed into the inlet 20, chamber 18, passages 32, whence it flows in spaces 45 along the convoluted and corrugated opposite face of the heat exchanger plate 10 in counter-current flow to the first fluid, emerging from the spaces 45 into passages 32, and then chamber 19 and outlet pipe 21. Thus, the device provides for a counter-current flow of the fluids, the optimum flow for effective heat exchange. If desired for certain applications, fluid flow in either side may be reversed, providing parallel flow.

The separator of FIGURE 8 is one form of separator which may be substituted for the separator of FIGURES 5 and 6 if it is desired to increase the effective fin area of

the separator and obtain improved heat transfer. Other separator shapes, including louvered or apertured separators, may also be used.

A modified type of heat exchanger plate having a convoluted surface which is provided with cross corrugations to increase turbulence of the fluid passing through the passages 44, 45 is shown in FIGURE 9. In forming this plate 50, the plate is first shaped into a plurality of closely-spaced corrugations 51, as close together as possible, after which the accordion-shaped plate is corrugated in the right-angle direction to form a series of shallower cross corrugations 52. The plate can then be folded into a plurality of convolutions, in the manner shown in FIGURE 3. Separator plates can be placed between the convolutions, and a heat exchanger structure completed in the manner shown in FIGURES 1 to 7. This type of structure requires a more resilient or ductile material.

The heat exchanger plate of FIGURE 10 is formed by corrugating and convoluting a ribbed sheet at an angle to the ribs. In the case of FIGURE 10 this angle is 90°. The sheet of FIGURE 10 is ribbed on both sides, although sheets ribbed only on one side may be used where flow conditions on the unribbed side do not require the presence of the ribs.

The ribbed sheet is formed by rolling a thicker sheet, or by welding, brazing or sintering strips to a flat sheet, or by other techniques as are known in the metal working art, and then corrugated and convoluted as heretofore described for a flat heat exchanger plate.

A fourth type of heat exchanger plate is shown in FIGURE 11. In this type, plate 60 is provided with a plurality of dimples 61, and then folded in a corrugated form as shown in the figure. The dimples also serve to increase turbulence, and are so spaced that a plurality of dimples appears in each corrugation of the plate.

The type of dimpled heat exchanger plate shown in FIGURE 12 is advantageous in providing a path for fluid to cross between corrugations. In this type the plate 70 is provided with a plurality of dimples or depressions 71 at the crests of the corrugations after having been folded in corrugated forms as shown in the figure. The dimples are regularly spaced, and also serve to increase turbulence.

In FIGURE 13, a heat exchanger of the invention adapted for use in connection with multiple fluids or multiple passes of the same fluid is shown. A single heat exchanger plate 10 formed in a plurality of convolutions having relatively small corrugations crosswise of the convolutions similar to that described above in connection with the previous embodiment, is disposed within a housing 1. The housing has one outlet pipe connection 17 and one inlet pipe connection (not shown) for fluid flow on one side of the plate and two inlet pipe connections 20a and 20b and two outlet pipe connections (not shown) for fluid flow on the other side of the plate. The housing is formed in two generally L-shaped segments 4 and 5 with the ends 9 of the convoluted heat exchanger plate 10 held firmly between them and welded together in a leak-proof seal. A single outlet chamber 11 is located on the one side of the heat exchanger plate for fluid flow on that side of the heat exchanger plate.

In order to form separate non-communicating segments on one side of the heat exchanger plate, a bond must be formed between the housing and the heat exchanger plate. This is accomplished in the embodiment shown by forming the L-shaped housing segment 5 with an indented portion 65 located between the inlet pipe connections 20a and 20b. The heat exchanger plate 10 is welded to this indented portion of the housing, thus forming two separate inlet chambers 12a and 12b on the same side of the exchanger plate. The weld is formed between the housing and one of the convolutions so that communication of fluid between the chambers 12a and 12b cannot occur. A rib or raised portions on the inside of the housing could also be used as the situs of the

weld to form separate chambers, and the housing need not be indented.

If desired, the indentation, rib or raised portion can be formed along the entire length of the housing and the plate can be welded thereto along its length. However, separate segments or chambers on one side of the plate can also be formed by dividing the heat exchanger plate into two plates, providing a slit or slot in the housing, extending the ends through the slot and bonding the end of each plate to the housing and to the other plate, at the slot to divide the heat exchanger plate into two non-communicating segments on the same side of the plate. This construction is similar to that used to bond the end of the plate to the housing segments.

It is also possible for the housing to closely abut and be welded to the heat exchanger plate along one of the convolutions to define separate segments or chambers. The abutting relationship of the housing and the plate can be seen by reference to FIGURE 4.

If desired, a combination of slots, indentations, or ribs can be used as the situs of the bond between the plate and housing. At the inlets and outlets it is desirable to form separate chambers by employing both an indentation and a slot between the inlets and outlets.

It is to be noted that it is also possible to provide separate chambers within the housing by employing a separator of greater length than those normally used between convolutions of the heat exchanger plate. Such a separator should be welded both to the housing and to the heat exchanger plate to define separate chambers or segments on each side of the plate. In this case, the housing need not be formed with an indented portion, rib, raised portion, or slot. If desired, a flat separator sheet can be used to facilitate bonding rather than the corrugated separator normally used.

In the assembly shown in FIGURE 13, one fluid can be used on the side of the plate communicating with the pipe connection 17, and two fluids, or one fluid that is passed through the heat exchanger twice, can be used on the side of the heat exchanger plate communicating with pipe connections 20a and 20b.

It can be seen that the fluid in the chamber 12a is kept separate from the fluid in the chamber 12b, by the weld of the heat exchanger plate 10 to the housing, and both of these fluids are separated from the fluid in chamber 11 by the heat exchanger plate.

Thus, two different fluids can be simultaneously passed in heat exchanger relationship with a third fluid on the opposite side of the exchanger plate without communication between any of the fluids. This can be done with any number of fluids or any number of passes on each side of the plate merely by forming additional chambers within the housing in the manner described above; only one heat exchanger plate need be used regardless of the number of fluids.

The heat exchanger of the invention is especially useful where the volume of space available for heat exchange is rather small, since it can be formed in a highly compact unit with a very high surface area without danger of plugging. It is useful both commercially and in aircraft and missiles, where space is at premium. The heat exchanger plate and separator construction makes it possible to form an extremely strong and rigid structure, capable of resisting very high fluid pressures and fluid pressure differentials across the heat exchanger plate, of the order of 1500 to 1300 p.s.i. and more. The construction is angular and flat, rather than circular, so that the formation of leakproof seals between the various connecting parts is facilitated, making the structure inexpensive to construct, and practically foolproof from the standpoint of developing leakage in use.

Having regard to the foregoing disclosure, the following is claimed as the inventive and patentable embodiments thereof;

1. A counterflow or parallel flow heat exchanger of the

plate type, comprising, in combination, a housing; openings in the housing for inflow and outflow of fluids between which heat is to be exchanged; a heat exchanger plate formed in a plurality of convolutions arranged in juxtaposed spaced-apart relationship, and having a corrugated surface, the corrugations of said surface being small relative to the convolutions of the plate and being disposed across said convolutions, the heat exchanger plate being disposed in the housing such that the ends of the convolutions define separate flow paths for the fluids between which heat is to be exchanged; and a plurality of separators disposed between the convolutions of the heat exchanger plate, and holding the convolutions in such spaced-apart relationship, the separators, convolutions and corrugations together being shaped to define a plurality of passages which are interconnected at a plurality of points along their length.

2. A heat exchanger in accordance with claim 1, in which the corrugations are smooth-surfaced.

3. A heat exchanger in accordance with claim 1, comprising a single corrugated and convoluted heat exchanger plate.

4. A heat exchanger in accordance with claim 1, in which the separators, convolutions and corrugations together define passages extending substantially the length and width of each convolution.

5. A heat exchanger in accordance with claim 1, in which the separators are formed in corrugations for increased surface area.

6. A heat exchanger in accordance with claim 5, in which the separator corrugations run crosswise to the plate corrugations.

7. A heat exchanger in accordance with claim 5, in which the depth of the separator corrugations corresponds to the width of the space between the apices of the plate corrugations.

8. A heat exchanger in accordance with claim 5, in which the apices of the separator corrugations are bonded to the apices of the plate corrugations.

9. A heat exchanger in accordance with claim 1, in which the heat exchanger plate is provided with cross-corrugations in addition to corrugations for increased turbulence.

10. A heat exchanger in accordance with claim 1, wherein the heat exchanger plate is provided with raised portions in addition to corrugations for increased turbulence of fluid flow along the surface thereof.

11. A heat exchanger in accordance with claim 10, in which the raised portions are in the form of dimples.

12. A heat exchanger in accordance with claim 10, in which the raised portions are in the form of ribs.

13. A heat exchanger in accordance with claim 1, wherein the convolutions are substantially parallel.

14. A heat exchanger in accordance with claim 1, wherein the convolutions are spaced in a V-configuration.

15. A heat exchanger in accordance with claim 1, comprising flat separators and plate corrugations formed with depressed portions to provide the interconnections between the passages.

16. A heat exchanger in accordance with claim 1, in which the heat exchanger is provided with means forming separate chambers within the housing to adapt the heat exchanger for use in connection with multiple fluids or multiple passes of the same fluid.

17. A heat exchanger in accordance with claim 1, in which the housing is provided with an indented portion that is bonded to the heat exchanger plate to form separate chambers within the housing.

18. A heat exchanger in accordance with claim 1, in which the housing is bonded to a separator extending from the heat exchanger plate to form separate chambers within the housing.

19. A heat exchanger in accordance with claim 18, in which the separator is bonded to the heat exchanger plate, as well as to the housing.

20. A heat exchanger in accordance with claim 1, in which the housing has a raised portion on the inside thereof and the raised portion is bonded to the heat exchanger plate to form separate chambers in the housing.

21. A heat exchanger in accordance with claim 1, including two heat exchanger plates, each having an end which is disposed through a slot in the housing at which each plate is bonded to the housing and to the other plate to define separate chambers in the housing.

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