ABSTRACT: A system is provided for achieving extremely high efficiencies in counterflow heat exchangers having multiple passageways, despite unavoidable passageway variations due to manufacturing tolerances and other causes. The individual passageways are configured with selected cross-sectional variations in dimension disposed in selected fashion along their lengths. These variations cause flow impedance of the passageways to vary in response to temperature differences of the flowing gases, and are arranged to act in compensatory senses, so that the temperatures are equalized. It is shown that adequate compensation is achieved to normalize flows and minimize temperature differentials between counterflowing fluids and adjacent passageways, thus to provide an optimized heat transfer effectiveness.
FLOW COMPENSATOR FOR EXCHANGER APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to systems for property interchange utilizing countercurrent flows and in particular to heat exchangers utilizing a multiplicity of countercurrent fluid flows.

2. History of the Prior Art

"Property interchange" as used herein refers to the effect on properties of countercoupling masses produced by interaction among the masses. The interaction actually comprises a transfer of a thing (either mass or energy) whose measurable manifestation is in the property as, for example, in the case of temperature interchange and heat transfer or concentration exchange and ion transfer. The terms "thing exchange" and "property exchange" (or interchange) will hereinafter be occasionally used interchangeably to refer to property exchange (or interchange) or to thing transfer as defined above, in the interest of conformance to established usage, as in the case of a heat exchanger. The precise meaning will be clear from the context.

Countercurrent property exchangers are built up of adjoining fluid flow paths in which streams of fluid flow in opposite senses separated by membranes or other structures through which transfer of mass or energy occurs. Exchangers of the countercurrent type have great potential efficiency, and at least one heat exchanger system is known having efficiencies in excess of 99 percent. This interchange efficiency generally increases with decreasing flow path cross section. Efficiency, however, is subject to impairment due to nonuniformity of distribution of mass flow between mass flow paths or nonuniform property distribution along the length of the paths, frequently resulting from nonuniformity in size and shape of the constraints containing the mass flows. This limitation on efficiency becomes increasingly significant with decrease of path cross section.

Mass flow and property distribution are subject to other system or environmental parameters than size of flow path cross section. Flow is dependent on pressure at the ends of the mass flow paths, on the longitudinal property distribution and often on temperature, for example. Property distribution is dependent on flow and often on temperature. Thus, variation of any of these parameters will affect efficiency.

An important special case involves heat exchangers utilizing countercoupling liquids. Here the measure of efficiency is temperature exchange effectiveness, which term is defined in more detail below.

For the most efficient property exchangers and specifically for the heat exchanger application, property interchange efficiency is increased as cross-sectional area of flow path decreases with more intimate contact between the countercoupling fluids. In such highly efficient interchange systems the problem of nonuniform flow becomes significant due to variations in passageway cross section resulting from fabrication tolerance limits, since with constant temperatures and pressures at the ends of the passageways more gas will flow through a passageway of larger cross section than through one of smaller cross section. If there is, for example, a tolerance limit range of ±5 percent in diameter of passageways, substantial problems arise in maintaining theoretically expected heat exchange efficiency under uniform flow conditions. For variations in flow and property distribution beyond a certain small range, the net result of the variations over the entire system of flows does not average to results approximating those expected under conditions of uniform flow and property distribution.

SUMMARY OF THE INVENTION

Flow differences due to changes in flow and property distribution parameters in countercurrent property interchange systems comprising a multiplicity of countercurrent fluid flows in accordance with the present invention, are confined within a narrower range than the range of variations in the parameters. In general terms, such exchangers in accordance with the invention suppress variations in flow and property distribution and efficiency due to variations in the related parameters by means of appropriately structuring the basic shape of the flow paths. Flow and property distribution variations are confined to a sufficiently narrow range within which the net effect of the variations over the flow paths of the entire system tends toward an average approximating the condition of uniform flow and property distribution.

In a specific example of the invention as applied to a heat exchange system, passageways comprising flow paths for a cold gas are shaped so that the primary resistance to flow, which will be designated hereinafter as "resistance", occurs at points of the passageways which are such that impedances are substantially independent of temperature, or in some forms generally much less dependent on temperature than the impedances for adjoining hot gas passageways. The hot gas passageways are shaped so that their areas of maximum impedance are in the region of the heat exchanger in which temperature change due to flow variation is greatest. At these points in the hot gas passageways which are directly related to temperature, will increase with increasing temperature brought on by increased flow or by variation in some other parameter affecting temperature distribution in the same sense, with a suppressant effect on that flow and on the variation in temperature distribution. The cold gas passageways, having a flow substantially independent of temperature or much less dependent than the hot gas passageways, experience relatively little, if any, change in flow due to change in the cross-sectional dimensions.

Further, in accordance with the invention, passageway shapes are provided exhibiting the effect of suppression of variations in mass flows due to differences in cross-sectional dimensions of the passageways containing the mass flows so as to achieve flow variations within the range where their effects tend to average to the results achievable under conditions of uniform flow.

As a result of the invention, a high efficiency heat exchanger of the counterflow type, whose flow paths are subject to random cross-sectional size variations within fabrication tolerance limits, is provided having an efficiency deviating very little from that achievable in the case of uniform path size, the exchanger being such that such variations in size would otherwise cause substantial diminution of efficiency. Copending application SER. NO. 794,905 filed Jan. 28, 1969 and assigned to the assignee of the present invention provides a context for the present invention. The referenced application describes a heat exchanger having multiple extremely small passageways arranged in matrix fashion and with the passageways for oppositely flowing fluids being interspersed in checkerboard fashion in one example.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the invention may be had from a consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic representation of one arrangement illustrative of the principle of the invention;

FIG. 2a is a plan sectional view of a pair of counterflow passageways of a property exchanger in accordance with the invention;

FIG. 2b is a plan sectional view of a pair of counterflow passageways of a property exchanger in accordance with the invention;

FIG. 3 is a perspective view, partially broken away, of one particular arrangement of a heat exchanger in accordance with the invention.

FIG. 4 is an end sectional view of passageways in the arrangement of FIG. 3 taken along the line 4—4.

FIG. 5 is a plan sectional view of a pair of passageways such as may be employed in the arrangement of FIG. 3.
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FIG. 6 is a plan sectional view of an alternative arrangement of passageways which may be employed in the arrangement of FIG. 3.

FIG. 7 is a plan sectional view of yet another alternative arrangement of passageways which may be employed in the arrangement of FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is applicable generally to all situations in which property or property state exchange takes place between differing separated flows subject to constraints confining them to flow paths, the thing being transferred being related to a measurable property of the flows, and the flow rate being related to the distribution of the property along the length of the flow paths. The distribution of the property along the length of the flow paths refers to the readings obtainable from measurement of the property along the length of the passageway.

In the schematic representation of FIG. 1, boundary elements 10, 11, 12 represent generalized limits on the volume of each of first and second volumetric flows in property exchange relation. The boundary elements 10, 11, 12 need not be physical elements; they may, for example, represent fields as in the case of plasma. Boundary elements 10, 11, 12, 13, 15 of the flow paths 13, 15 for a first and second mass flow, respectively. Flow path 13 includes variable flow impedance means 14 dependent upon a property of the flow. Flow path 15 includes property independent impedance means 16. Both the property independent impedance 16 and the property dependent impedance 14 may be material or not. The property dependent impedance 14 is most efficiently placed at the point of the second flow path at which the property which is a measurable manifestation of the thing being transferred (hereinafter designated as "the property") changes most rapidly with a change in the second flow.

FIGS. 2a and 2b illustrate a special case of the situation of FIG. 1 in which a hot gas flows through passageways 18, 28 being constrained within its flow path by material passageway walls 20, 22 and 30, 32 respectively. The thing being transferred is heat, the transfer taking place through the passageway walls 22, 32, the property is temperature. Pinched passageways 18, 28 have pinches 24, 34, respectively, at their midpoints, comprising temperature dependent impedances.

This increases the rate of temperature, substantially more sharply than it would in the case of a passageway of uniform cross-sectional area. The pinched passageways 18, 28 narrow toward their midpoints and widen toward their ends. Bowed passageways 30, 40 adjoin pinched passageways 18, 28, respectively, and are defined by passageway walls 32, 31 and 32, 41 respectively. Restrictions 26, 27 and 36, 37 at both ends of bowed passageways 30, 40 respectively comprise temperature independent impedances. The bowed passages thus broaden at their midpoints and narrow at their ends. FIGS. 2a and 2b represent an embodiment of the invention as a heat exchanger with compensation for nonuniform mass distribution in the flow paths. In the arrangement of FIGS. 2a and 2b, the heat exchanger passageways exhibit random cross-sectional size variations within defined fabrication tolerance limits, and the pinched passageways 18, 28 are assumed to have dimensions at the high and low ends, respectively, of the tolerance range. Bowed passageways 30, 40 are assumed to have dimensions at the low and high ends of the tolerance range, respectively.

In pinched passageway 18, there is a greater hot gas flow than there is in a passageway not subject to tolerance size variation, that is, one whose size is at the midpoint of the size range. Bowed passageway 30 experiences a decrease in mass flow through it. The excessive flow through pinched passageway 18 and the diminished flow through bowed passageway 30 produce a greater temperature along the length of the pinched passageway than that in the case of passageways not subject to size variations, the greatest change in temperature occurring in the region of pinch 24. The impedance resulting from the pinch, which is temperature dependent, is increased, thus limiting the excess gas flow resulting from the excessive passageway size and limiting the consequent increase in temperature along the length of passageway 18. Pinched passageway 28 undergoes a reverse series of events. The gas flow through it is decreased from that in passageways not subject to size variations, the temperature along it is lessened, and the impedance due to the pinch is less, thus compensating for limiting flow insufficiency through pinched passageway 28. The flow through bowed passageways 30, 40 is substantially temperature independent due to the location of the pinches 19, thus, they provide a stable average flow with respect to the hot gas flow. The net effect over the two passageway pairs discussed is a suppression of flow variations within narrow enough limits so that they average over the two sets of passageways, with the result that the average temperatures at the ends do not differ significantly from those expected in the case of uniform passageway size and uniform fluid flow. In one example, dimensional variations in a ±5 percent tolerance range otherwise resulting in ±20 percent flow variation are limited by the invention to producing a ±2 percent flow variation. As discussed above, passageway size is only one flow parameter; variations in other flow parameters such as pressure or temperature, would be similarly limited in their effect on flow.

FIGS. 3 and 4 show a heat exchanger embodiment of the invention utilizing two different mass flows, gases A (the first gas) and B (the second gas) for heat exchange. A heat exchanger 50 (FIG. 3) is comprised of a multiplicity of fluid flow passageways 52 (best seen in FIG. 4) which are formed in a laminate comprising alternate layers of corrugated membranes 54 and planar membranes 56. Heat transfer takes place through passageway walls, which may be of low heat conductivity material (to avoid longitudinal conduction) but are thin enough not to interpose an effective barrier to heat transfer. The passageways 52 are defined by the points of contact of the corrugated membranes 54 with the adjacent planar membrane. Every membrane thus forms a partial boundary of two sets of passages, an upper and lower set, which are each divided into a multiplicity of individual passageways, the other boundaries of the passageways being the adjacent planar support membranes.

As shown in FIG. 4, the gases flow through the passages in a checkerboard pattern such that a flow of one of the gases is surrounded by flows of the other gas in the opposite direction. It should be noted that a two-gas model of the heat exchanger system is described for convenience; more than two gases may be easily accommodated in the same or equivalent structure. In the two-fluid model, the checkerboard fluid flow pattern is achieved by introducing each gas by header means (not shown) alternately into upper and lower passages on successive levels of the laminate. Thus in an upper level 53 of FIG. 4, the B gas is shown flowing above the corrugated membrane 54 in separate passageways in an upper passage, and the A gas flows below the membrane 54 in separate passageways in a lower passage, the pattern being the opposite in a next lower level 55.

Membranes 54 are of finely corrugated plastic (the height of the corrugations being approximately 0.01 inch in one example) shaped by thermoforming to have a high heat exchange area-to-volume ratio. The B gas enters the heat exchange system 50 through side header means (not shown), passes through a header injection-transition region 51 into a heat exchange volume 58 located in the central region of the heat exchanger 50, and leaves the heat exchanger through second header means (not shown) after flowing through a header expulsion-transition region 57. The heat exchange system at a first longitudinal end 57, passes through the heat exchange volume 58 and exits at a second longitudinal end 59.

A measure of the efficiency of the heat exchanger as described above is provided by temperature exchange effectiveness which may be defined quantitatively as follows:

Tuating effectiveness
where TEE represents temperature exchange effectiveness, \( \Delta T \) represents temperature differential between the counter-flowing gases at one end of the heat exchanger, and \( \Delta T_e \) represents the change in temperature in a gas between opposite ends of the heat exchanger. This of course assumes that \( \Delta T \) is small compared with \( \Delta T_e \), which is the case in heat exchangers in accordance with the present invention. Maintenance of the temperature differential at the ends critically depends on uniformity of mass flow through the heat exchanger, as indicated by the following specific example. Assume two passageway pairs of paired counterflowing gases at differing temperatures. In the first pair the hotter gas (designated the “hot gas”) is present in excess; the cold gas, in an amount “normal” for the system. The converse is true for the second pair. The flow of hot gas in the first pair is assumed equal to the flow of cold gas in the second pair. In the first pair the excess of hot gas flowing into the passageway at the hot end of the heat exchanger will leave the heat exchanger at the cold end, that is, the end in which the cold flow enters. The hot gas will be inadequately cooled, causing the temperature differential at the cold end to be greater than the temperature differential for uniform flow. In the second passageway pair, excess cold gas causes the hot gas exiting at the cold end to be cooler than it would be in the case of uniform flow. Generally, averaging over such sets of pairs does not give results similar to those produced by uniform flow, the net effect being an upward dislocation at the cold end of the temperature of the exiting hot gas. Temperature exchange effectiveness is thus diminished.

The problem to which the present invention is directed results from the necessity for dimensional tolerances in the fabrication of the passageways of the heat exchanger. Where the mass flow is evenly divided among all of the individual passageways (the ideal case) a transfer efficiency closely approximating 100 percent is expected. With truly uniform passageways an efficiency of 99.7 percent should be realized. With heat exchanges of the type described as actually constructed, it has been found that the realized heat efficiency is on the order of 90 percent. The manufacturing tolerance in the cross-sectional dimensions of the individual passageways is ±5 percent. Analysis of the problem indicates that any variation in passageway dimension has the same restricting effect on the hot fluid as on the cold fluid in the respective passageways. Consequently the effects of variations of individual passageway size do not even out from one pair to another, and the effectiveness of the heat transfer is significantly limited by comparison to the effectiveness of a structure of perfectly uniform passageways.

Flow variations are often due to dimensional variations in passageway size within fabrication tolerance limits as discussed above. An analysis, accurate to the first order, of the relationship among mass flow rate, and temperature exchange efficiency is based on the McAdams reference given below. Under this analysis, the change in flow, designated \( \Delta f \), related to the change in diameter, designated \( \Delta d \), as follows:

\[
\Delta f = 4 \times \Delta d
\]

This applies for ±\( \Delta d \). The maximum temperature exchange effectiveness achievable under circumstances of deviation from uniform flow is approximately as follows:

\[
\text{TEE} = 100\% \Delta T_f / \Delta T_e \] 2

where \( \Delta T_f \) is defined as the change in flow due to the maximum change in diameter, i.e., at the ends of the tolerance range. Substitution of \( \Delta T_f = \Delta T_e \) becomes \( \text{TEE} = 100\% - 2 \times \Delta d \). Thus, tolerance limits of ±5 percent produce approximately a 90 percent ceiling on efficiency.

The present invention utilizes generally for property interchanges the principle expressed in a book entitled "Heat Transfer" by McAdams. William H. McAdams, McGraw-Hill Book Co., Inc. (3rd ed. 1954) that, given a heat exchanger of multiple materials with an efficiency close to 100 percent for uniform flow, variations in flow over the heat exchanger within a range whose limits (in percent) are equal in magnitude to the difference between the uniform flow efficiency percentage and 100 percent will produce good averaging over the totality of passageways to approximate the uniform flow case.

Compensation for the manufacturing tolerances in the dimensions of the individual passageways can be realized in accordance with the invention by removing the dependence of the gas flow and property transfer on the passageway dimensions as fabricated. This is accomplished by constructing particular portions of the passageways in a manner such that the impedance of an individual passageway is substantially determined by the impedance of the particular portion. This portion is then located, relative to the flow within the passageway and the property distribution along its extent, to develop an impedance to flow which is temperature dependent in the passageways carrying the hotter of the counter-flowing gases but which is relatively temperature insensitive in the passageways carrying the cooler of the counter-flowing gases. Thus, in a hot gas passageway which would normally transport gas at a higher flow rate because of being slightly oversized (due to the manufacturing tolerance) and correspondingly reduce the heat transfer effectiveness, the resulting increase in temperature at localized impedance portion causes a corresponding increase in impedance which tends to limit the flow to that which would obtain in a passageway of design dimensions, thus improving the overall efficiency to that which is predicted for a truly uniform structure. The inverse occurs in hot gas passageways of undersize dimensions with the same advantageous result of improvement in overall efficiency through compensation for reduced flow rate.

In FIG. 5, a pinched passageway 70, defined by walls 72, 74, which carries a hot gas, narrows at approximately its midpoint, where it forms a pinch 76. The pinch 76 is such that the passageway 70 narrows sufficiently to provide the necessary suppressant effect for passageway deviations for the particular system. The pinch 76 is located within heat exchange volume 58 of FIG. 3. Opposite ends 78 and 80 of the pinched passageway 70 have a cross-sectional width approximately twice that of the cross-sectional width at the pinch 76, the width at pinch 76 being in one embodiment 0.012 inch and that at ends 78 and 80 0.026 inch. An adjoining bowed passageway 82 has its greatest width at a bow 84 which is adjacent to pinch 76 in the same central region within the heat exchanger volume 58. The bowed passageway 82 narrows from the middle to the ends 85 and 86 where it has its smallest cross-sectional extent. In the same example as that for which specific dimensions were given in connection with pinched passageway 70, the cross-sectional width at the bow 84 is 0.026 inch while the ends 85 and 86 have a width of 0.012 inch. In this example, the passageway boundaries are not curved; rather, they are straight lines, being so constructed for reasons of convenience of fabrication. The basic rectangular form of the heat exchanger is that of one particular embodiment; the invention is not limited to heat exchangers of rectangular form.

It should be noted that liquids instead of gases may be used for purposes of heat or other property exchange. When heat is the property being exchanged, the dominance of the viscosity of the liquid with respect to flow impedance and the decrease of this viscosity with increase in temperature requires that the hot liquid pass through the bowed passageways and the cold liquid through the pinched passageways. The situation in which the counterflowing masses are in the gaseous state. Generally, when flow impedance is inversely related to the property of the mass flow which is the measurable manifestation of the thing which is being exchanged, the mass flow which contains the greater amount of the thing being exchanged must pass through the bowed passageways, whereas, the situation is reversed when impedance is directly related to the property.

The above discussion obtains when a suppression of the effect of parameter change on the related system characteristics
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is desired. In certain uses of the heat exchanger, it may be desirable to magnify system changes rather than to suppress them as, for example, when the system output is used to monitor, measure, or control changes in input. In such a case, the positions of hot and cold gases would be reversed.

In an actual heat exchanger embodiment in accordance with FIG. 3, the efficiency to be expected for uniform mass flow is about 99.7 percent. The actual efficiency for random variations in passageway size within tolerance limits of 5 percent is about 99 percent. The efficiency of the same heat exchanger modified in accordance with the present invention is a least 99.2 percent. This invention thus makes use of the countercutting heat exchangers of small passageway diameter practical by enabling actual manufactured structures to develop efficiencies within the range of theoretically ideal structures. Since efficiency increases with decrease in passageway size as in the case of the heat exchanger of FIG. 3 the present invention in its application to countercutting heat exchangers represents a significant advance over the prior art.

FIG. 6 is a schematic representation of an alternative embodiment of the invention. There is no property independent impedance in the embodiment of FIG. 6.

The heat exchanger application of an alternative compensation arrangement. FIG. 6, a hot gas passageway 90 and a cold gas passageway 92 adjacent each other. The hot gas passageway 90 is defined by constraints forming a flow path in the form of passageway walls 94, 96. Wall 94 is of the same form as passageway wall 20 of FIG. 2. Wall 96 is substantially linear and parallel to a passageway wall 98, with which it forms a passageway 92 is substantially uniform cross-sectional area throughout its length. It thus exhibits a measure of temperature dependent flow impedance. A similar analysis to that in the discussion of FIG. 2 applies to the situation of FIG. 6. The major difference between the situations is in the temperature dependence of the impedance of passageway 92. The temperature increase due to excess gas flow through passageway 90 is thus sharpened by the increased impedance, brought on by the increased temperature, to the flow of cold gas through passageway 92. Thus, the suppressing and compensating effect of the increased impedance of passageway 90 with respect to the flow of hot gas is less than in the FIG. 2 situation. It is found, however that within appropriate limits, the arrangement of FIG. 6 allows effective suppression of, and compensation for flow and temperature deviations. This is chiefly a consequence of the smallness of the temperature dependence of the impedance of passageway 92 in relation to the temperature dependence of the impedance of passageway 90. The actual relation of the impediment required to achieve the desired suppression can be determined by theory or experiment. Such a desired relation will be designated as one where one impedance is substantially more temperature dependent (or property dependent, in the general case) than the other. An arrangement like that shown in FIG. 6 may be preferable in some cases to that of FIG. 2 on structural or other grounds.

FIG. 7 illustrates another heat exchanger embodiment of the invention. In FIG. 7, are shown a pair of passageways 100, 102 for hot and cold gas flows respectively, defined by constraints forming flow paths in the form of passageway walls 104, 106, 108. The walls 104, 106 forming passageway are substantially linear and parallel; passageway 100 is of substantially uniform cross-sectional area through its length. Passageway wall 108 is of similar bowed shape to passageway wall 20 of FIG. 2.

As in the situation of FIG. 6, both passageways comprise temperature dependent impedances. Also as in the situation there, the temperature dependence of the hot gas passageway under proper conditions may be substantially more sharp than that of the cold gas passageway so as to admit of the averaging effect. This configuration is useful in a practical example in which solidified impurities in the hot gas flow would impact about a pinch like that of FIG. 2.

Although a number of alternative forms and modifications of systems in accordance with the invention have been described, it will be appreciated that the invention is not limited thereto but encompasses all variations and modifications falling within the scope of the appended claims.

What is claimed is:
1. A heat exchanger providing high thermal transfer effectiveness comprising:
   a matrix of longitudinal passageways for countercflowing fluids, the passageway for one of the fluids being interspersed among passageways for the other of the countercflowing fluids, said passageways being defined by walls transferring heat laterally therethrough between the passageways, the required thermal transfer effectiveness being sufficiently high that the differences in the cross-sectional dimensions of the passageways due to manufacturing tolerances tend to result in unequal flows therethrough, with consequent loss of effectiveness of undesirable extent;
   flow impedance varying means comprising means providing variations in selected regions of the cross-sectional dimensions of the passageways, the variations for one fluid being different along the length of the passageways from those for the other fluid, such variations in dimension being of sufficient extent and in proper sense to change the flow impedance of the passageway in response to the temperature of the fluid therein to compensate for manufacturing tolerance deviations, whereby the flows in the passageways are compensated to establish selected nominal thermal gradients along the length of the passageways and in each of the passageways, whereby the exchanger has thermal transfer effectiveness approaching the optimum.
2. The invention as set forth in claim 1 above, wherein the longitudinal passageways defining the heat exchanger matrix are disposed in checkerboard fashion between the passageways for the two types, so that a passageway for one fluid is substantially encompassed by passageways for the other fluid, and heat transfer takes place laterally in an omidirectional manner through the intervening walls.
3. The invention as set forth in claim 2 above, wherein the passageways for one fluid are of smallest dimension in a central region along the lengths thereof, and wherein the passageways for the other fluid are of smallest dimension adjacent the ends thereof.
4. The invention as set forth in claim 3 above, wherein the passageways for one fluid are bowed convexly along their lengths and the passageways for the other fluid are bowed concavely along their lengths.
5. The invention as set forth in claim 4 above, wherein the smallest dimension regions have transverse dimension of approximately half the largest dimension regions of said passageways.
6. A heat exchanger providing high thermal transfer effectiveness comprising:
   a matrix of longitudinal passageways for countercflowing fluids, the passageways for one of the fluids being interspersed among passageways for the other of the countercflowing fluids, said passageways being defined by walls transferring heat laterally therethrough between the passageways, the required thermal transfer effectiveness being sufficiently high that the cross-sectional variations in the dimensions of the passageways due to manufacturing tolerances result in undesirable unequal flows therethrough;
   and flow impedance varying means comprising means providing variations in the cross-sectional dimensions of the passageways, for a least one of the fluids, said variations being disposed in at least one selected region along the length of said passageways, the variations in dimension being of sufficient size to change the impedance to flow of a passageway in response to the temperature of the fluid therein, the change being of a sense whereby the
flows in the passageways are compensated to tend to establish selected nominal temperature levels and thermal gradients along the length of the passageways.

7. A heat exchanger comprising a plurality of passageways for opposite flow of two fluids, the passageways being arrayed so that each passageway for a fluid is substantially surrounded by passageways for the other fluid, said passageways being separated by walls for lateral transfer of heat between counterflows passing therethrough, said passageways including means providing variable flow impedance responsive to fluid flow temperature through said passageways, and said variable flow impedance means acting in opposite senses in passageways for the different fluids;

and means for feeding countercflowing fluids to said passageways so that each of said passageways is surrounded by passageways for an opposing countercflow.

8. The invention as set forth in claim 7 wherein said means providing variable flow impedance comprises restricted portions within said passageways.

9. The invention as set forth in claim 7 wherein the impedance means comprise flow paths of substantially uniform cross-sectional dimensions further including second impedance means comprising constrictions adjacent both ends in others of said flow paths.

10. A heat exchanger in accordance with claim 7 wherein said flow impedance means comprises a restriction selectively located within at least one of said passageways, said restriction is provided by a pinched passageway, the passageway being in the form of a pair of cones joined at the apex with the pinch being approximately midway between the ends of the passageway.

11. A heat exchanger in accordance with claim 10 further including an expanded passageway adjacent the pinched passageway and having an expanded portion matching the configuration of the pinch.

12. A heat exchanger in accordance with claim 10 wherein the lateral dimension of the pinch portion of the passageway is approximately one-half of the lateral dimension of the end portions of the passageway.

13. A heat exchanger in accordance with claim 7 wherein said flow impedance means comprises a restriction selectively located within at least one of said passageways a substantially unrestricted passageway adjacent the restricted passageway, said restricted passageway having a concave side and a substantially straight side, the latter side being common with the unrestricted passageway.