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(54) Title: MODULAR HEAT EXCHANGER

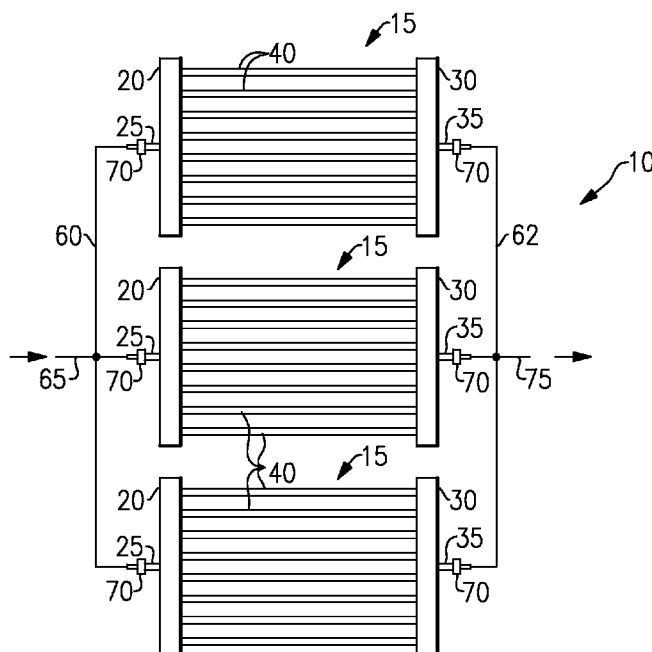


FIG. 1

(57) Abstract: A modular multi-channel tube heat exchanger includes a plurality of aluminum heat exchanger modules selectively connected in fluid communication by interconnecting tubing. Each heat exchanger module includes an aluminum inlet header, an aluminum outlet header and a plurality of aluminum heat exchange tubes extending longitudinally therebetween. Each of the plurality of heat exchange tubes may have a plurality of flow paths extending longitudinally in parallel relationship from an inlet end thereof in fluid communication with the inlet header to an outlet end thereof in fluid communication with the outlet header.

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MODULAR HEAT EXCHANGER

Field of the Invention

[0001] This invention relates generally to heat exchangers having a plurality of heat transfer tubes extending between a first header and a second header, also sometimes referred to as manifolds, and, more particularly, to modular multi-channel tube heat exchangers.

[0002] Refrigerant vapor compression systems are well known in the art. Air conditioners and heat pumps employing refrigerant vapor compression cycles are commonly used for cooling or cooling/heating air supplied to a climate-controlled comfort zone within a residence, office building, hospital, school, restaurant or other facility. Refrigerant vapor compression systems are also commonly used for cooling air or other secondary fluid to provide a refrigerated environment for food items and beverage products within, for instance, display cases in supermarkets, convenience stores, groceries, cafeterias, restaurants and other food service establishments.

[0003] Commonly, these refrigerant vapor compression systems include a compression device, a refrigerant heat rejection heat exchanger, an expansion device and a refrigerant heat absorption heat exchanger connected in serial refrigerant flow communication in a refrigerant vapor compression cycle. In a subcritical refrigerant vapor compression cycle, the refrigerant heat rejection heat exchanger functions as a condenser. In a transcritical refrigerant vapor compression cycle, however, the refrigerant heat rejection heat exchanger functions as a gas cooler. In either a subcritical or transcritical refrigerant vapor compression cycle, the refrigerant heat absorption heat exchanger functions as an evaporator. Additionally, conventional refrigerant vapor compression systems sometimes include one or more refrigerant-to-refrigerant heat exchangers, for example, an economizer heat exchanger or a suction line-to-liquid line heat exchanger, or air-to-refrigerant heat exchanger, such as a reheat heat exchanger or an intercooler.

[0004] Historically, the refrigerant heat rejection heat exchanger and the refrigerant heat absorption heat exchanger used in such refrigerant vapor compression systems have been round tube and plate fin heat exchangers constituting a plurality of

round tubes, typically having a diameter of ½ inch, 3/8 inch or 7 millimeters, disposed in a desired circuiting arrangement, with each circuit defining a refrigerant flow path extending between a pair of headers or manifolds. Thus, a round tube and plate fin heat exchanger with conventional round tubes will have a relatively small number of large flow area refrigerant flow paths extending between the headers. Generally, both the tubes and headers of round tube heat exchangers are made of copper, which facilitates assembly of these heat exchangers, and also simplifies connection to the copper refrigerant lines of the refrigerant vapor compression system, by simple brazing or soldering. Additionally, leaks in copper tubes or their connections may be easily repaired both in the factory and in the field by either brazing or soldering or potentially removing and replacing the leaking tube or the leaking section of a tube. The round tubes of the round tube and plate fin heat exchangers are typically expanded to make a good mechanical and thermal contact with the plate fins. The plate fins are typically made from aluminum or copper and represent a secondary extended heat transfer surface.

[0005] More recently, flat, rectangular or oval shape, multi-channel tubes are being used in heat exchangers for refrigerant vapor compression systems. Sometimes, such multi-channel heat exchanger constructions are referred to as microchannel or minichannel heat exchangers as well. Each multi-channel tube has a plurality of flow channels extending longitudinally in parallel relationship the length of the tube, each channel defining a small cross-sectional flow area refrigerant path. Thus, a heat exchanger with multi-channel tubes extending in parallel relationship between a pair of headers or manifolds of the heat exchanger will define a relatively large number of small cross-sectional flow area refrigerant paths extending between the two headers. To provide a multi-pass flow arrangement within a multi-channel heat exchanger core, the headers, which in some embodiments may be intermediate manifolds, may be divided into a number of chambers, which depends on a desired number of refrigerant passes.

[0006] Great Britain Patent No. 938,888 discloses a heat exchanger plate made up of a plurality of elongated hollow box-section sub-units secured together in side-by-side contact by welding, epoxy resin adhesive or clamping to provide a complete plate. Header means at the ends of the sub-units connect the sub-units in series, parallel, or a

series-parallel combination with respect to the flow of coolant or refrigerant through the sub-units.

[0007] U.S. Patent No. Re. 35,502 discloses an evaporator for a refrigeration system which is a heat exchanger having a plurality of hydraulically parallel flow paths defined by heat exchange tubes, an inlet header, an outlet header and a pair of intermediate headers. A first row of tubes extends between the inlet header and a first intermediate header and a second row of tubes extends between a second intermediate header and the outlet header, the first and second intermediate headers are disposed in side-by-side relationship and interconnected in flow communication at the respective ends by U-shaped tubes.

[0008] To reduce the cost of the multi-channel heat exchanger, it is known to assemble the heat exchanger from extruded or welded aluminum tubes and aluminum headers/manifolds, and, if desired, aluminum fins disposed between adjacent tube pairs. Once the multi-channel, flat tube heat exchanger has been assembled, the entire assembled heat exchanger must be placed in a brazing furnace to bond the aluminum components together. As a consequence, the overall size of the heat exchanger is limited by the size of the available brazing furnaces.

Summary of the Invention

[0009] A modular multi-channel tube heat exchanger comprises a plurality of aluminum heat exchanger modules selectively connected in fluid communication by tubing, such as copper or aluminum tubing, in a parallel flow configuration, a series flow configuration or a combined parallel/series flow configuration.. Each heat exchanger module includes at least a first aluminum header, at least a second aluminum header and at least one aluminum heat exchange tube extending longitudinally therebetween. Each header of the heat exchanger module may function as an inlet header or an outlet header or an intermediate header, depending on the refrigerant flow path configuration within that heat exchange module. The at least one heat exchange tube may comprise a plurality of heat exchange tubes. Each tube may have a plurality of flow paths extending longitudinally in parallel relationship from an inlet end thereof in fluid communication with the first header to an outlet end thereof in fluid communication with the second

header. A plurality of heat transfer tubes within each heat exchanger module may have straight or serpentine configuration, multiple or single flow channels, and round or flattened cross-section. The first aluminum header and the second aluminum header of each one of the plurality of heat exchanger modules is connected by a copper or aluminum tube in fluid flow communication to at least one of the first aluminum header and the second aluminum header of another one of the plurality of heat exchanger modules.

[0010] In an embodiment, each of the first and second aluminum headers of the at least one of the plurality of heat exchanger modules includes an aluminum or brass nipple that is attached to the connecting tube by a mechanical connection, such as a threaded connection, a compression connection or an adhesive bonding connection. In an embodiment, each of the first and second aluminum headers of the at least one of the plurality of heat exchanger modules includes an aluminum or brass nipple that is attached to the connecting tube by a thermal bonding connection, such as a solder connection, a brazed connection or a metal-to-metal thermal diffusion connection.

[0011] In an embodiment, each of the first and second aluminum headers of the at least one of the plurality of heat exchanger modules includes a copper nipple that is connected to a copper connecting tube by a thermal bonding connection, such as a solder connection, a brazing connection, or a metal-to-metal thermal diffusion connection. In an embodiment, each of the first and second aluminum headers of the at least one of the plurality of heat exchanger modules includes a copper nipple that is connected to a copper connecting tube by a mechanical connection, such as a threaded connection, a compression connection or an adhesive bonding connection.

Brief Description of the Drawings

[0012] For a further understanding of the invention, reference will be made to the following detailed description of the invention which is to be read in connection with the accompanying drawing, wherein:

[0013] FIG. 1 is a schematic illustration of a first exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0014] FIG. 2 is a schematic illustration of a second exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0015] FIG. 3 is a schematic illustration of a third exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0016] FIG. 4 is a side elevation view of a fourth exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0017] FIG. 5 is a schematic illustration of a fifth exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0018] FIG. 6 is a schematic illustration of a sixth exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0019] FIG. 7 is a schematic illustration of a seventh exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0020] FIG. 8 is a schematic illustration of a eighth exemplary embodiment of a modular, multi-channel heat exchanger in accord with the present invention;

[0021] FIG. 9 is a perspective view of a section of a heat exchanger module of a modular, multi-channel heat exchanger in accord with the present invention; and

[0022] FIG. 10 is a schematic illustration of an exemplary variable arrangement of heat exchanger modules dependant on a mode of operation for a refrigerant system in accord with the present invention

Detailed Description of the Invention

[0023] The modular, multi-channel heat exchanger 10 of the invention will be described in general herein with reference to the various exemplary embodiments depicted in FIGs. 1-8. However, the depicted embodiments are illustrative and are not intended to limit the invention. It is to be understood that the modular, multi-channel tube heat exchanger 10 of the invention may be comprised of any number of a plurality of heat exchanger modules arranged in various configurations.

[0024] In each of the illustrated exemplary embodiments shown in FIGs. 1-4, the heat exchanger 10, in its simplest configuration, includes a plurality, that is two or more, single pass, parallel-tube, mutli-channel tube heat exchanger modules 15. In the exemplary embodiment depicted in Figure 1, the heat exchanger 10 comprises three heat

exchanger modules 15 arranged in a parallel configuration, with respect to refrigerant flow. In the exemplary embodiment depicted in FIG. 2, the heat exchanger 10 comprises a pair of heat exchanger modules 15 arranged in a series flow configuration, with respect to refrigerant flow. In the exemplary embodiment depicted in FIG. 3, the heat exchanger 10 comprises a pair of heat exchanger modules 15 arranged in a parallel configuration, with respect to refrigerant flow, with respect to each other, and arranged in a series flow configuration, with respect to refrigerant flow, with an additional heat exchanger module 15 disposed downstream, with respect to refrigerant flow, thereof. In the exemplary embodiment depicted in FIG. 4, the heat exchanger 10 comprises three heat exchanger modules 15A arranged in a parallel configuration, with respect to refrigerant flow, with respect to each other and arranged in a series flow configuration, with respect to refrigerant flow, with an additional heat exchanger module 15B disposed downstream, with respect to refrigerant flow, thereof.

[0025] Referring now to Figures 1-4 in particular, each single-pass heat exchanger module 15 includes a plurality of longitudinally extending multi-channel heat exchange tubes 40 thereby providing a plurality of fluid flow paths between an inlet header 20 and an outlet header 30. The inlet header 20 defines a fluid chamber for collecting refrigerant, or other primary heat exchange fluid, and distributing the collected refrigerant, or other primary heat exchange fluid, amongst the plurality of heat exchange tubes 40. The outlet header 30 defines a fluid chamber for collecting refrigerant or other primary heat exchange fluid having traversed the heat exchange tubes 40 and passing the collected refrigerant, or other primary heat exchange fluid, from the heat exchanger module 15 downstream. Each heat exchange tube 40 has an inlet at one end in fluid flow communication to the inlet header 20 and an outlet at its other end in fluid flow communication to the outlet header 30. In the exemplary embodiments of the heat exchanger 10 depicted in FIGs. 1-3, each of the heat exchange modules 15 is depicted with their respective heat exchange tubes 40 arranged in parallel relationship extending generally horizontally between a generally vertically extending inlet header 20 and a generally vertically extending outlet header 30. In the exemplary embodiment of the modular heat exchanger 10 depicted in FIG. 4, each of the heat exchange modules 15 is depicted with their respective heat exchange tubes 40 arranged in parallel relationship

extending generally vertically between a generally horizontally extending inlet header 20 and a generally horizontally extending outlet header 30.

[0026] Referring now to FIGs. 5 and 6, each heat exchanger 10 includes a plurality of multi-pass, parallel-tube, multi-channel tube heat exchanger modules 15'. In the exemplary embodiment depicted in FIG. 5, the heat exchanger 10 includes two heat exchanger modules 15' disposed in a parallel flow configuration, with respect to fluid flow through the heat exchange tubes 40 thereof, with the heat exchange tubes 40 of each of the heat exchanger modules 15' being arranged in a two-pass configuration. In this embodiment, each module 15' has a first portion of the heat exchange tubes 40 that extend between an inlet header 20 and an intermediate header 80 and a second portion of the heat exchange tubes 40 that extend between the intermediate header 80 and an outlet header 30. The inlet header 20 and the outlet header 30 comprise separate sections of a common manifold structure.

[0027] In the exemplary embodiment depicted in FIG. 6, the heat exchanger 10 includes three heat exchanger modules 15' disposed in a parallel flow configuration, with respect to fluid flow through the heat exchange tubes 40 thereof, with the heat exchange tubes 40 of each of the heat exchanger modules 15' being arranged in a four-pass configuration. In this embodiment, each module 15' has a first portion of the heat exchange tubes 40 that extend between an inlet header 20 and a first section of a first intermediate header 80, a second portion of the heat exchange tubes 40 that extend between the first section of the first intermediate header 80 and a second intermediate header 90, a third portion of the heat exchange tubes 40 that extend between the second intermediate header 90 and a second section of the first intermediate header 80, and a fourth portion of the heat exchange tubes 40 that extend between the second section of the first intermediate header 80 and an outlet header 30. The inlet header 20, the second intermediate header 90 and the outlet header 30 may comprise separate sections of a common manifold structure, as depicted in FIG. 6.

[0028] Referring now to FIGs. 7 and 8, each heat exchanger 10 depicted therein includes a plurality of multi-pass, serpentine, multi-channel tube heat exchanger modules 15''. In the exemplary embodiment depicted in FIG. 7, the heat exchanger 10 includes two heat exchanger modules 15'' disposed in a parallel flow configuration with respect to

fluid flow through the serpentine heat exchange tubes 40' thereof, with the two serpentine heat exchange tubes 40' of each of the heat exchanger modules 15'' extending between an inlet header 20 and an outlet header 30 in a four-pass arrangement. In the exemplary embodiment depicted in FIG. 8, the heat exchanger 10 includes three heat exchanger modules 15'' disposed in a parallel flow configuration, with respect to fluid flow through the serpentine heat exchange tubes 40' thereof, with the three serpentine heat exchange tubes 40' of each of the heat exchanger modules 15'' extending between an inlet header 20 and an outlet header 30 in a three-pass arrangement.

[0029] Referring now to FIG. 9, each heat exchange tube 40 has a plurality of parallel flow channels 42 extending longitudinally, i.e. parallel to the axis of the tube, along the length of the tube thereby providing multiple, independent, parallel flow paths between the inlet of the tube and the outlet of the tube. Each multi-channel heat exchange tube 40 is a “flat” tube of, for instance, rectangular, racetrack or oval cross-section, defining an interior which is subdivided to form a side-by-side array of independent flow channels 42. The flat, multi-channel tubes 40 may, for example, have a width of fifty millimeters or less, typically twelve to twenty-five millimeters, and a height of about two millimeters or less, as compared to conventional prior art round tubes having a diameter of ½ inch, 3/8 inch or 7 mm. The tubes 40 are shown in the drawing hereof, for ease and clarity of illustration, as having ten channels 42 defining flow paths having a rectangular cross-section. However, it is to be understood that in practical applications, such as, for example, refrigerant vapor compression systems, each multi-channel tube 40 will typically have about ten to twenty flow channels 42, but may have a greater or a lesser multiplicity of channels, as desired. Generally, each flow channel 42 will have a hydraulic diameter, defined as four times the flow area divided by the “wetted” perimeter, in the range from about 200 microns to about 3 millimeters. Although depicted as having a rectangular cross-section in the drawings, the channels 42 may have a circular, triangular, trapezoidal cross-section or any other desired cross-section. Although multi-channel flattened aluminum heat exchange tubes such as the tubes depicted in FIG. 9 are discussed in connection with each of the exemplary embodiments of the invention illustrated in FIGs. 1-8, other tube configurations may be employed. For example, the heat exchange tubes 40 comprising single channel, flattened

aluminum heat exchange tubes or multi-channel, round aluminum heat exchange tubes or single channel, round aluminum heat exchange tubes, may also be employed in the heat exchanger modules of the modular heat exchanger 10 of the invention.

[0030] Depending on the particular application in which the modular heat exchanger 10 is to be used, the heat exchanger modules 15 may include heat transfer fins 50 positioned between adjacent heat transfer tubes 40 for heat transfer enhancement. The presence of fins 50 also enhances structural rigidity and heat exchanger design compactness. The fins 50 may be flat, as depicted in FIG. 9, or may have a wavy, corrugated or louvered design and typically form triangular, rectangular, offset or trapezoidal airflow passages. In the configuration of the heat exchanger module 15 depicted in FIG. 9, the heat exchange tubes 40 extend longitudinally in a generally horizontal direction and the fins 50 extend longitudinally in a generally vertical direction. However, in another configuration, the heat exchange tubes 40 may extend longitudinally in a generally vertical direction, and the fins 50 may extend longitudinally in a generally horizontal direction. In other embodiments, the heat exchange tubes 40 may extend longitudinally at an angle to the horizontal/vertical direction between a pair of headers that also extend at an angle to the horizontal/vertical direction.

[0031] In applications, whether the heat exchange tubes 40 are orientated horizontally or vertically or otherwise, a secondary fluid, such as air, flows through the heat exchanger module 15 and over the external surfaces of the heat exchange tubes 40 and the associated fins 50. The heat exchange tubes 40 extend transversely across the flow path of the secondary fluid with the leading edge 41 of each heat exchange tube 40 facing upstream into the incoming flow of secondary fluid. As the secondary fluid passes over the external surfaces of the heat exchange tubes 40 and the associated fins 50, heat exchange takes place between the secondary fluid and a primary fluid, such as refrigerant, water or glycol solution, flowing through the channels 42 of the multi-channel heat exchange tubes 40. When the heat exchanger 10 is used in a refrigerant vapor compression system, such as in refrigeration and air conditioning applications, the primary fluid is a refrigerant and the secondary fluid is generally air to be cooled if the heat exchanger 10 is employed as an evaporator, or refrigerant heat absorption heat

exchanger, or air to be heated if the heat exchanger 10 is employed as a condenser or a gas cooler and functions as a refrigerant heat rejection heat exchanger.

[0032] To reduce cost and simplify assembly, each multi-channel tube heat exchanger module 15 may be made of aluminum, as opposed to copper. The heat exchange tubes 40 are typically extruded or welded aluminum tubes. The headers/manifolds 20 and 30 are formed of aluminum, and, the fins 50, if provided, are made from an aluminum sheet as well. After the heat exchanger module 15 has been assembled with brazing compound applied as in conventional practice at contacting surfaces between the heat exchange tube 40 and associated fins 50 and between the ends of the heat exchange tubes 40 and the respective headers 20 and 30, the entire assembled heat exchanger module 15 is placed in a brazing furnace to permanently bond the aluminum components together. Some other components, such as manifold caps, connecting tube stubs and brackets, can be also permanently attached during the furnace brazing of the heat exchange module 15.

[0033] As noted previously, the modular, multi-channel tube heat exchanger 10 is constructed from a plurality of heat exchanger modules 15 connected in refrigerant flow communication with each other. For example, two or more heat exchanger modules 15 may be connected together by means of copper or aluminum refrigerant lines 60. In an embodiment, the aluminum inlet header 20 is provided with a copper or brass inlet nipple 25 attached permanently to the aluminum header, during the brazing operation conducted at the manufacturing plant after the furnace brazing operation, during manufacturing of the heat exchanger module 15. Similarly, in this embodiment, the aluminum outlet header 30 is provided with a copper or brass outlet nipple 35 attached permanently to the aluminum header, during the brazing operation conducted at the manufacturing plant after the furnace brazing operation, during manufacturing of the heat exchanger module 15. With this construction, the heat exchanger 10 may be readily assembled in the field or at the manufacturing plant by soldering copper refrigerant lines 60 to the appropriate copper inlet and outlet nipples of the respective heat exchanger modules 15. In this manner, the heat exchanger 10 may be readily assembled in any desired size and configuration simply by linking the appropriate number of aluminum heat exchanger modules 15 in the desired refrigerant circuit flow arrangement. Further, the inlet nipple

25 and the outlet nipple 35 may be made from aluminum and attached respectively to the headers 20 and 30 during the same furnace brazing process. In this case, connecting refrigerant lines 60 made from copper or aluminum may be attached to the nipples 25 and 35 by the brazing process after the furnace brazing operation. Other thermal bonding connections, such as a metal-to-metal thermal diffusion connection, may also be used to join nipples and connecting tubes made of similar metals, such as a copper nipple to a copper tube or an aluminum nipple to an aluminum tube.

[0034] In an embodiment, the aluminum inlet header 20 is provided with a threaded inlet nipple 25 attached permanently to the aluminum header, during the brazing operation conducted at the manufacturing plant, generally after the furnace brazing operation, during manufacturing of the heat exchanger module 15. Similarly, in this embodiment, the aluminum outlet header 30 is provided with a threaded outlet nipple 35 attached permanently to the aluminum header, during the brazing operation conducted at the manufacturing plant after the furnace brazing operation, during manufacturing of the heat exchanger module 15. With this construction, the heat exchanger 10 may be readily assembled in the field or at the factory by mechanically connecting the refrigerant lines 60, generally made out of copper, aluminum or stainless steel, to the appropriate threaded inlet or outlet nipples of the respective heat exchanger modules. In this manner, the heat exchanger 10 may again be readily field or factory assembled in any desired size and configuration simply by linking the appropriate number of aluminum heat exchanger modules 15 connected by refrigerant lines in the desired refrigerant circuit flow arrangement using threaded mechanical connections. Other mechanical connections, such as a compression connection or a chemical bonding connection, such as for example glue or other adhesive, may be used to join nipples and connecting tubes made of dissimilar metals, such a copper nipple to an aluminum tube or an aluminum nipple to a copper tube.

[0035] Referring now to Figure 1 in particular, the heat exchanger 10 depicted therein comprises three heat exchanger modules 15 arranged in a parallel configuration, with respect to refrigerant flow. The aluminum inlet headers 20 of the three heat exchanger modules 15 are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at

connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 that is in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the three heat exchanger modules 15 are connected in refrigerant flow communication by refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70 to return refrigerant to the refrigerant circuit via a refrigerant line 75 that is in flow communication with each of the refrigerant lines 62. In this manner, the flow of refrigerant, or other primary fluid, flows in parallel through the three heat exchanger modules 15. The heat exchanger modules 15 are generally disposed in a planar arrangement so that the air, or other secondary fluid secondary fluid, flowing therethrough has the same, or about the same, temperature passing through the respective heat exchanger modules.

[0036] Referring now to FIG. 2 in particular, the heat exchanger 10 depicted therein comprises a pair of heat exchanger modules 15 arranged in a series flow configuration, with respect to refrigerant flow. The two aluminum heat exchanger modules 15 are connected in refrigerant flow communication by a refrigerant line 64 extending between the outlet nipple 35 of the aluminum outlet header 30 of the upstream heat exchanger module 15 and the inlet nipple 25 of the aluminum inlet header 20 of the downstream heat exchanger module 15 at connection points 70 so that the flow of refrigerant, or other primary fluid, is arranged in series through the two heat exchanger modules 15. The inlet nipple 25 of the inlet header 20 of the upstream heat exchanger module 15 is connected to the refrigerant line 65 of the refrigerant circuit to receive refrigerant from the refrigerant circuit. The outlet nipple 35 of the outlet header 30 of the downstream heat exchanger module 15 is connected to the refrigerant line 75 of the refrigerant circuit to return refrigerant to the refrigerant circuit. The heat exchanger modules 15 are disposed in a planar arrangement so that the air, or other secondary fluid, flowing therethrough preferably has the same, or about the same, temperature passing through the respective heat exchanger modules.

[0037] Referring now to FIG. 3 in particular, the heat exchanger 10 comprises a pair of upstream heat exchanger modules 15 arranged in a parallel configuration, with respect to refrigerant flow, with respect to each other and arranged in a series configuration, with respect to refrigerant flow, with an additional heat exchanger module

15 disposed downstream, with respect to refrigerant flow thereof. The aluminum inlet headers 20 of the first two upstream heat exchanger modules 15 are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at the connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the two heat exchanger modules 15 are connected in refrigerant flow communication by the refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at the connection points 70. The refrigerant lines 62 are in flow communication with a refrigerant line 64 which is connected to the inlet nipple 25 of the inlet header 20 of the third downstream heat exchanger module 15. The outlet nipple 35 of the outlet header 30 is connected to a refrigerant line 75 to return refrigerant to the refrigerant circuit via the refrigerant line 75. In this manner, the flow of refrigerant, or other primary fluid, passes in parallel arrangement through the first and second upstream heat exchanger modules and thence in series through the third downstream heat exchanger module. The three heat exchanger modules 15 may be disposed in a planar arrangement so that the air, or other secondary fluid, flowing therethrough has the same, or about the same, temperature passing through the respective heat exchanger modules.

[0038] Referring now to FIG. 4 in particular, the heat exchanger 10 comprises three upstream heat exchanger modules 15A arranged in a parallel configuration, with respect to refrigerant flow, with respect to each other and collectively arranged in a series flow configuration, with respect to refrigerant flow, with a fourth heat exchanger module 15B disposed downstream, with respect to refrigerant flow thereof. In the depicted embodiment, the three upstream heat exchanger modules 15A are disposed in a stack arrangement, rather than a planar arrangement, whereby air, or other secondary fluid, passes in series through the stacked heat exchanger modules as indicated in FIG. 4. Refrigerant, or other primary fluid, flows through the downstream-most (with respect to air flow) three heat exchanger modules 15A in parallel and thence proceeds through the upstream-most (with respect to air flow) heat exchanger module 15B which is disposed in series refrigerant flow relationship with the other three heat exchanger modules 15A. This arrangement of the heat exchanger modules 15A and 15B is exemplary, and in many

cases, it would be desirable to have a combination of planar and serial configurations, with respect to the airflow, of the heat exchanger modules 15A and 15B. For instance, for the condenser or gas cooler applications, the highest efficiency may be achieved if the heat exchanger modules 15A are arranged in a planar configuration with each other, with respect to the airflow, and positioned downstream, with respect to the airflow, of the heat exchanger module 15B. Many other configurations accommodating various applications would be also feasible and within the scope of the invention.

[0039] The aluminum inlet headers 20 of the three heat exchanger modules 15A are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at connection points 70 to receive refrigerant from the refrigerant circuit via the refrigerant line 65 in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the three heat exchanger modules 15A are connected in refrigerant flow communication by the refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70. The refrigerant lines 62 are in flow communication with the refrigerant line 64 which is connected to the inlet nipple 25 of the inlet header 20 of the fourth heat exchanger module 15B. The outlet nipple 35 of the outlet header 30 of the fourth heat exchanger module 15B is connected to the refrigerant line 75 to return refrigerant to the refrigerant circuit.

[0040] Referring now to FIG. 5, as noted before, the heat exchanger 10 includes two heat exchanger modules 15' disposed in a parallel flow configuration, with respect to fluid flow through the heat exchange tubes 40 thereof, with the heat exchange tubes 40 of each of the heat exchanger modules 15' being configured in a two-pass arrangement. The aluminum inlet headers 20 of the two heat exchanger modules 15' are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 that is in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the two heat exchanger modules 15' are connected in refrigerant flow communication by refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70 to return refrigerant to refrigerant line 75 of the refrigerant circuit

that is in flow communication with each of the refrigerant lines 62. Additionally, the two intermediate headers 80 are interconnected in refrigerant flow communication by refrigerant equalization lines 66 connected at one end to the nipple 85 of the first of the intermediate headers 80 and at its other end to the nipple 85 of the second of the intermediate headers 80.

[0041] The refrigerant equalization lines 66 provide several important functions improving performance of the modular heat exchanger 10. The most significant two functions are the equalization of the refrigerant pressure in the intermediate headers 80 of different heat exchanger modules 15', and proper redistribution of the liquid refrigerant phase of the two-phase refrigerant mixture accumulated in the intermediate headers 80. The former function allows for the uniform operation of the heat exchange tubes 40 within the first and second passes positioned within different heat exchanger modules 15'. The later function allows for the reduction or elimination of refrigerant maldistribution associated with the second refrigerant pass. Refrigerant maldistribution between the heat exchange tubes 40 significantly reduces performance of the heat exchangers, and may be particularly pronounced for microchannel or minichannel heat exchangers. Therefore, dividing the refrigerant flow between the heat exchanger modules 15' and providing refrigerant flow communication means, such as the refrigerant equalization lines 66, between the intermediate headers 80 of different heat exchanger modules 15', equalizes the liquid refrigerant phase content within the intermediate headers 80, improves refrigerant distribution amongst the heat exchange tubes 40 within the downstream pass and enhances overall performance of the modular heat exchanger 10.

[0042] Referring now to FIG. 6, as noted before, the heat exchanger 10 depicted therein comprises three heat exchanger modules 15' arranged in a parallel configuration, with respect to refrigerant flow. Each of the heat exchanger modules 15' comprises a four-pass heat exchanger module having a first manifold sectioned into an inlet header 20, an outlet header 30 and an intermediate header 90 disposed therebetween and a second manifold sectioned into a pair of intermediate headers 80A and 80B. The aluminum inlet headers 20 of the three heat exchanger modules 15' are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet

nipples 25 of the aluminum inlet headers 20 at connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 that is in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the three heat exchanger modules 15' are connected in refrigerant flow communication by refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70 to return refrigerant to refrigerant line 75 of the refrigerant circuit that is in flow communication with each of the refrigerant lines 62. Additionally, the two intermediate headers 80A are interconnected in refrigerant flow communication by a refrigerant equalization line 64 connected to the respective nipples 85 of the two intermediate headers 80A and the three intermediate headers 80B are interconnected in refrigerant flow communication by refrigerant equalization lines 68 connected to the respective nipples 85 of each of the intermediate headers 80B. All benefits provided by the refrigerant equalization line 64 of the FIG. 5 embodiment are applicable to the refrigerant equalization lines 64 and 68 of the FIG. 6 embodiment as well.

[0043] Referring now to FIG. 7, as noted before, the heat exchanger 10 includes two heat exchanger modules 15'' disposed in a parallel flow configuration, with respect to fluid flow through the serpentine heat exchange tubes 40 thereof, with the serpentine heat exchange tubes 40 of each of the heat exchanger modules 15'' being configured in a four-pass arrangement. The aluminum inlet headers 20 of the two heat exchanger modules 15'' are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 that is in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the two heat exchanger modules 15'' are connected in refrigerant flow communication by refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70 to return refrigerant to a refrigerant line 75 of the refrigerant circuit that is in flow communication with each of the refrigerant lines 62.

[0044] Referring now to FIG. 8, as noted before, the heat exchanger 10 includes three heat exchanger modules 15'' disposed in a parallel flow configuration, with respect to fluid flow through the serpentine heat exchange tubes 40 thereof, with the serpentine

heat exchange tubes 40 of each of the heat exchanger modules 15'' being configured in a three-pass arrangement. The aluminum inlet headers 20 of the three heat exchanger modules 15'' are connected in refrigerant flow communication by refrigerant lines 60 connected to the respective inlet nipples 25 of the aluminum inlet headers 20 at connection points 70 to receive refrigerant from the refrigerant circuit via a refrigerant line 65 that is in flow communication with each of the refrigerant lines 60. The aluminum outlet headers 30 of the three heat exchanger modules 15'' are connected in refrigerant flow communication by refrigerant lines 62 connected to the respective outlet nipples 35 of the aluminum outlet headers 30 at connection points 70 to return refrigerant to a refrigerant line 75 of the refrigerant circuit that is in flow communication with each of the refrigerant lines 62.

[0045] The heat exchanger configurations discussed hereinbefore are exemplary. Because the heat exchanger 10 of the invention is of a modular in design, that is, composed of two or more heat exchanger modules 15, 15' or 15'' the heat exchanger 10 can be selectively sized by connecting any desired number of heat exchanger modules 15, 15' or 15'' together in either parallel flow or series flow or mixed parallel and series flow arrangements, with respect to refrigerant flow, and also, independently of the refrigerant flow configuration, connecting the heat exchanger modules 15, 15' or 15'' together in either parallel flow configuration or series flow configuration or mixed parallel and series flow configuration, with respect to air flow. The heat exchanger modules 15, 15' or 15'' may also be configured in parallel flow, counter-flow or mixed parallel/counter-flow arrangements, with respect to heat exchange between the refrigerant flow and the air flow. The modular nature of the heat exchanger 10 also facilitates the design of a heat exchanger 10 of selectively variable configuration having a first configuration for operation in a first mode and a second configuration for operation in a second mode, such as, for example, for in heat pump applications wherein the heat exchanger functions as a condenser (or a gas cooler) in one of the cooling or heating modes of operation and as an evaporator in the other of the cooling or heating modes of operation.

[0046] An exemplary variable configuration of the modular heat exchanger 10 including two heat exchanger modules 15 is shown in FIG. 10, where, for instance, the modular heat exchanger 10 either functions as a condenser (the refrigerant flow is shown

by solid arrows) in one of the cooling or heating modes of operation or functions as an evaporator (the refrigerant flow is shown by dashed arrows) in the other cooling or heating modes of operation. When the modular heat exchanger 10 operates as a condenser, a check valve 102 allows the refrigerant flow through the heat exchanger modules 15 in sequence, while check valves 104 and 106 are closed, by pressure differentials, preventing refrigerant flow through refrigerant lines 108 and 110. When the modular heat exchanger 10 operates as an evaporator, the check valve 102 is closed, by the pressure differential, and the check valves 104 and 106 are open, due to pressure differentials, allowing refrigerant flow through the heat exchanger modules 15, connected by the refrigerant lines 110 and 108 at the inlet and outlet respectively, in parallel. The check valves 102, 104 and 106 can be replaced by solenoid valves, if desired. Other refrigerant flow control devices as well as their locations and arrangements are also feasible.

[0047] Other examples when variable heat exchanger configurations are highly desirable and conveniently provided by the modular heat exchanger 10 include activation and deactivation of the heat exchanger modules 15, 15' or 15'' depending on the environmental conditions and the type of cooling mode of operation. The former applications comprise, but are not limited to, reduction of a number of parallel heat exchanger modules 15, 15' or 15'' to prevent oil retention within the heat exchanger with reduced refrigerant flow rate, for instance, at lower temperatures, or bypassing some of the sequential heat exchanger modules 15, 15' or 15'' when the pressure drop for the heat exchanger 10 becomes excessive or when different sensible and latent loads are required for the evaporator. The latter applications include, for instance, sharing the heat exchanger modules 15, 15' or 15'' between the evaporator and reheat heat exchanger while switching between cooling and reheat modes of operation, or between the condenser (or gas cooler) and intercooler while operating refrigerant systems with multiple compression stages. As in the embodiment depicted in FIG.10, all these various arrangements and configuration can be provided, for instance, by appropriate refrigerant flow control devices such as valves located in the refrigerant conduits interconnecting the heat exchanger modules 15, 15' or 15'' so as to permit individual modules to be selectively activated and deactivated for various functions depending upon the

configuration desired for a particular operating mode and environmental conditions. Valves may also be installed as appropriate in the conduits connecting the heat exchanger modules 15, 15' or 15'' to permit the refrigerant flow configuration between the heat exchanger modules 15, 15' or 15'' to be selectively reconfigured and to permit the heat exchange relationship between refrigerant flow and air flow to be selectively reconfigured from parallel flow to counter-flow through any particular module.

[0048] Additionally, the heat exchanger modules 15, 15' and 15'' may be standardized, allowing optimization of the manufacturing process, increase of production volumes and subsequent price reduction. The modular design of the heat exchanger 10 of the invention also facilitates field repairs in that if a leak develops in a heat exchange tube 40 or 40' or a header of an individual heat exchanger module 15, 15' or 15'', that heat exchanger module may be removed by un-soldering/ un-brazing or un-threading at the connections 70.

[0049] In each of the exemplary embodiments of the heat exchanger 10 depicted in FIGs. 1-8, each header is depicted as having one flow connection nipple. However, if desired, multiple flow connection nipples may be provided on any header, whether inlet, outlet or intermediate, for better refrigerant distribution or other purpose. Further, in heat pump applications, the modular heat exchanger 10 has to accommodate flow reversals throughout the refrigerant system while operational modes are switched between cooling and heating. Under such circumstances, the heat exchanger performing the heat rejection function in the cooling mode of operation has to perform the heat absorption function in the heating mode of operation, and vice versa. Thus, the arrows in the Figures are pointing in one way only depicting the direction of flow of refrigerant, or other primary heat exchange fluid, in a single mode of operation for illustration purposes only.

[0050] The modular heat exchanger 10 could be easily configured to accommodate straight-through refrigerant pass configuration of the parallel heat exchanger modules 15, e.g. of FIG. 1, as well as converging/diverging refrigerant pass arrangement of the sequential heat exchanger modules 15, e.g. of FIG. 2, and parallel-series configuration of the heat exchanger modules 15, e.g. of the FIG.3. As known, in many cases, for optimal performance, it is desired to have converging refrigerant pass

arrangement for the condenser applications and diverging refrigerant pass configuration for the evaporator applications.

[0051] As noted previously, the connections 70 may be made by thermal bonding, for example soldering or brazing or metal-to-metal diffusion, if the inlet and outlet nipples 25 and 35 are made out of compatible metals, such as copper or aluminum, or by mechanical or chemical connection, for example a threaded connection, a compression connection or a chemical bonding connection, if the inlet and outlet nipples 25 and 35 are made, for instance, out of aluminum, copper, brass or stainless steel, whether similar or dissimilar metals are involved.

[0052] While the present invention has been particularly shown and described with reference to the exemplary embodiments as illustrated in the drawing, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the spirit and scope of the invention as defined by the claims.

We Claim:

1. A modular heat exchanger comprising:
a plurality of heat exchanger modules, each heat exchanger module includes a first aluminum header, a second aluminum header and at least one aluminum heat exchange tube having an inlet in fluid communication with said first aluminum header and an outlet in fluid communication with said second aluminum header, said at least one heat exchange tube defining at least one fluid flow passage extending between said first aluminum header and said second aluminum header for conveying a first fluid internally therethrough in heat exchange relationship with a second fluid passing externally of said at least one heat exchange tube, said plurality of heat exchanger modules arranged in one of a parallel flow configuration, a series flow configuration or a combined parallel/serial flow configuration with respect to said first fluid and independently arranged in one of a parallel flow configuration, a series flow configuration or a combined parallel/serial flow configuration with respect to said second fluid.
2. A modular heat exchanger as recited in claim 1 wherein said at least one heat exchange tube comprises a plurality of heat exchange tubes extending between said first and second aluminum headers, each of said plurality of heat exchange tubes defining a plurality of discrete fluid flow passages extending longitudinally between said first and second aluminum headers.
3. A modular heat exchanger as recited in claim 2 wherein said plurality of heat exchange tubes comprises a plurality of straight heat exchange tubes extending between said first and second aluminum headers.
4. A modular heat exchanger as recited in claim 2 wherein said plurality of heat exchange tubes comprises a plurality of serpentine heat exchange tubes extending between said first and second aluminum headers.

5. A modular heat exchanger as recited in claim 1 wherein said first fluid comprises a refrigerant.

6. A modular heat exchanger as recited in claim 5 wherein said second fluid comprises air.

7. A modular heat exchanger as recited in claim 1 wherein said plurality of heat exchanger modules comprises at least a first heat exchanger module and a second heat exchanger module connected in a series flow configuration with respect to the flow of the first fluid, the second aluminum header of said first heat exchanger module connected in fluid flow communication with respect to the first fluid to the first aluminum header of said second heat exchanger module by a connecting line.

8. A heat exchanger as recited in claim 7 wherein the second aluminum header of said first heat exchanger module includes an aluminum outlet nipple and the first aluminum header of said second heat exchanger module includes an aluminum inlet nipple, the aluminum outlet nipple of the second aluminum header of said first heat exchanger module connected in fluid flow communication with respect to the first fluid to the aluminum inlet nipple of the first aluminum header of the second heat exchanger module by a copper tube, the copper tube connected to each of the aluminum inlet nipple and the aluminum outlet nipple by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

9. A heat exchanger as recited in claim 7 wherein the second aluminum header of said first heat exchanger module includes an aluminum outlet nipple and the first aluminum header of said second heat exchanger module includes an aluminum inlet nipple, the aluminum outlet nipple of the second aluminum header of said first heat exchanger module connected in fluid flow communication with respect to the first fluid to the aluminum inlet nipple of the first aluminum header of the second heat exchanger module by an aluminum tube, the aluminum tube connected to each of the aluminum

inlet nipple and the aluminum outlet nipple by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

10. A heat exchanger as recited in claim 7 wherein the second aluminum header of said first heat exchanger module includes a copper outlet nipple and the first aluminum header of said second heat exchanger module includes a copper inlet nipple, the copper outlet nipple of the second aluminum header of said first heat exchanger module connected in fluid flow communication with respect to the first fluid to the copper inlet nipple of the first aluminum header of the second heat exchanger module by a copper tube, the copper tube connected to each of the copper inlet nipple and the copper outlet nipple by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

11. A modular heat exchanger as recited in claim 1 wherein said plurality of heat exchanger modules comprises at a first heat exchanger module and a second heat exchanger module connected is a parallel flow configuration with respect to flow of the first fluid, the first aluminum headers of said first and second heat exchanger modules connected by a connecting line to a common source for the first fluid and the second aluminum headers of the said first and second heat exchanger modules connected by a connecting line to a common discharge for the first fluid.

12. A heat exchanger as recited in claim 11 wherein each of the first aluminum headers of each of said first and second heat exchanger modules includes an aluminum inlet nipple and each of the second aluminum headers of each of said first and second heat exchanger modules includes an aluminum outlet nipple, the aluminum inlet nipples of the first aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common source for the first fluid by a copper tube and the aluminum outlet nipples of the second aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common discharge for the first fluid by a copper tube, the copper tubes connected to the aluminum inlet nipples and the

aluminum outlet nipples by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

13. A heat exchanger as recited in claim 11 wherein each of the first aluminum headers of each of said first and second heat exchanger modules includes an aluminum inlet nipple and each of the second aluminum headers of each of said first and second heat exchanger modules includes an aluminum outlet nipple, the aluminum inlet nipples of the first aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common source for the first fluid by an aluminum tube and the aluminum outlet nipples of the second aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common discharge for the first fluid by an aluminum tube, the aluminum tubes connected to the aluminum inlet nipples and the aluminum outlet nipples by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

14. A heat exchanger as recited in claim 11 wherein each of the first aluminum headers of each of said first and second heat exchanger modules includes a copper inlet nipple and each of the second aluminum headers of each of said first and second heat exchanger modules includes a copper outlet nipple, the copper inlet nipples of the first aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common source for the first fluid by a copper tube and the copper outlet nipples of the second aluminum headers of said first and second heat exchanger modules connected in fluid flow communication with respect to the first fluid to a common discharge for the first fluid by a copper tube, the copper tubes connected to the copper inlet nipples and the copper outlet nipples by one of a mechanical connection, a thermal bonding connection and a chemical bonding connection.

15. A heat exchanger as recited in claim 1 wherein said plurality of heat exchanger modules are arranged in crossflow or cross-counterflow with respect to said second fluid.

16. A heat exchanger as recited in claim 1 further comprising at least one flow control device operatively associated with at least one heat exchanger module of said plurality of heat exchanger modules for selectively controlling the flow of said first fluid through said at least one heat exchanger module.

17. A heat exchanger as recited in claim 16 wherein said at least one flow control device has a first open position wherein a flow of said first fluid is passed through said at least one heat exchanger module operatively associated with said at least one flow control device and a second closed position wherein the flow of said first fluid through said at least one heat exchanger module operatively associated with said at least one flow control device is blocked.

18. A heat exchanger as recited in claim 17 wherein said at least one flow control device is selectively positioned in the first open position or the second closed position in response to a selected mode of operation, a selected environmental condition or a selected operating condition.

19. A heat exchanger as recited in claim 16 wherein said at least one flow control device has a first open position wherein said at least one heat exchanger module operatively associated with said at least one flow control device has first functionality and a second closed position wherein said at least one heat exchanger module operatively associated with said at least one flow control device has a second functionality.

20. A heat exchanger as recited in claim 19 wherein said at least one flow control device is selectively positioned in the first open position or the second closed position in response to a selected mode of operation, a selected environmental condition or a selected operating condition.

21. A heat exchanger as recited in claim 19 wherein said first functionality is a heat rejection heat exchanger function and said second functionality is an intercooler heat exchanger function, or said first functionality is an evaporator function and said second functionality is a reheat heat exchanger function.

22. A heat exchanger as recited in claim 1 wherein at least one of said plurality of heat exchanger modules comprises a single-pass heat exchanger module with respect to said first fluid.

23. A heat exchanger as recited in claim 1 wherein at least one of said plurality of heat exchanger modules comprises a multiple-pass heat exchanger module with respect to said first fluid.

24. A heat exchanger as recited in claim 1 wherein at least one header of at least one of said plurality of heat exchanger modules includes an intermediate manifold.

25. A heat exchanger as recited in claim 1 wherein at least one header of at least two of said plurality of heat exchanger modules includes an intermediate manifold and said intermediate manifolds are interconnected in fluid communication via an equalization line.

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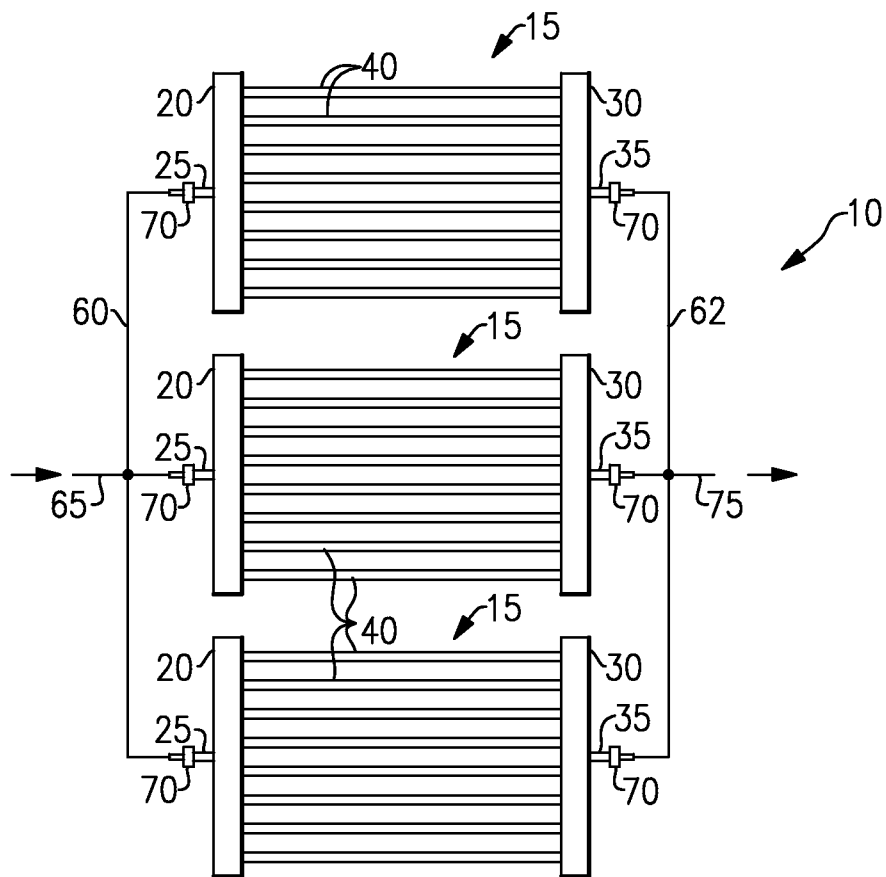


FIG. 1

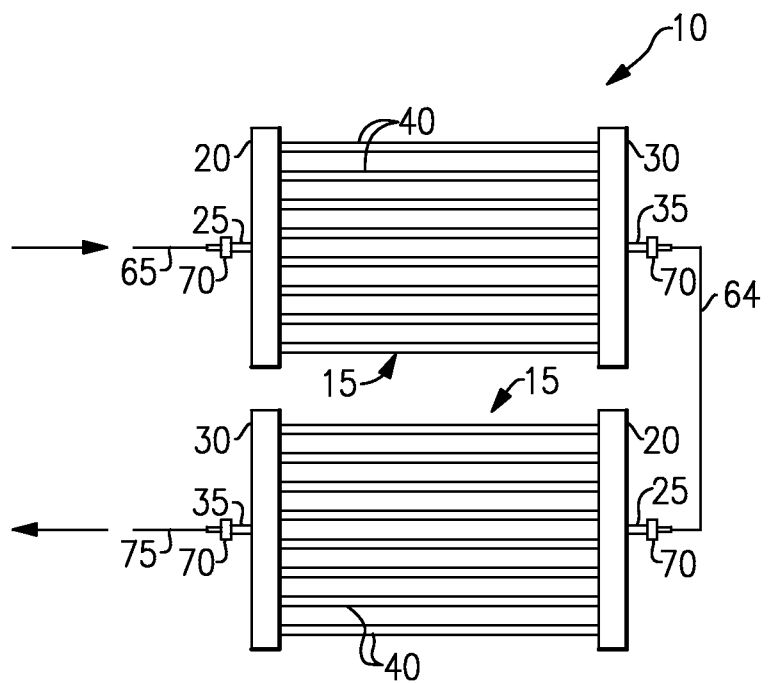


FIG. 2

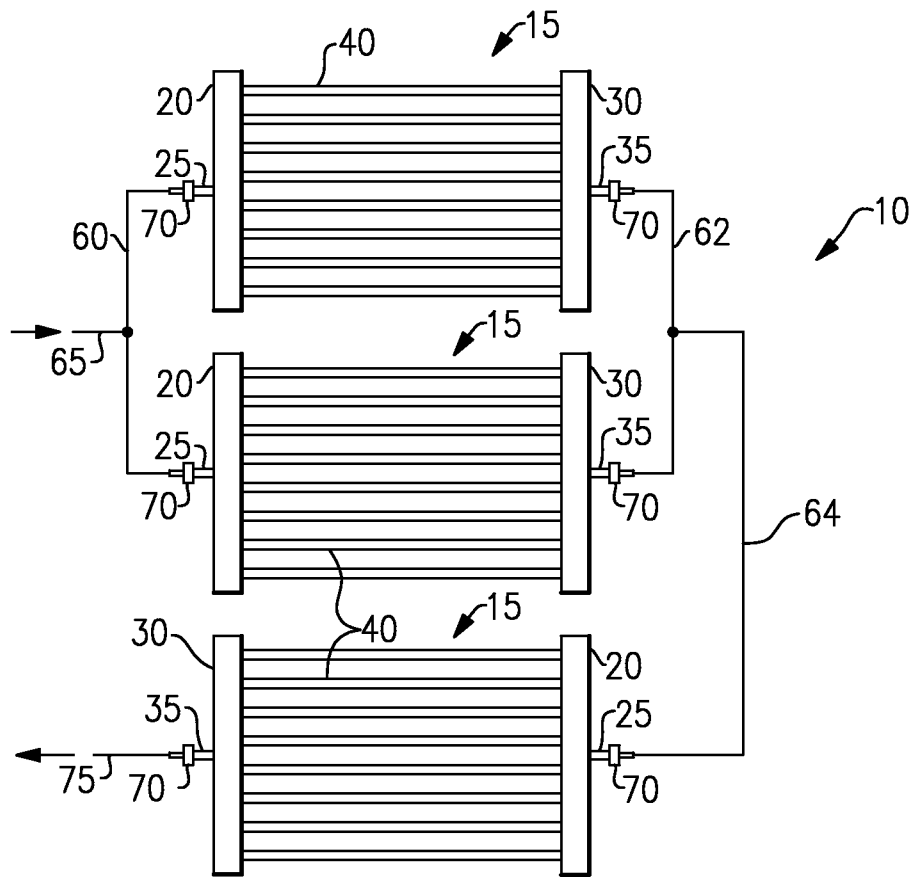


FIG.3

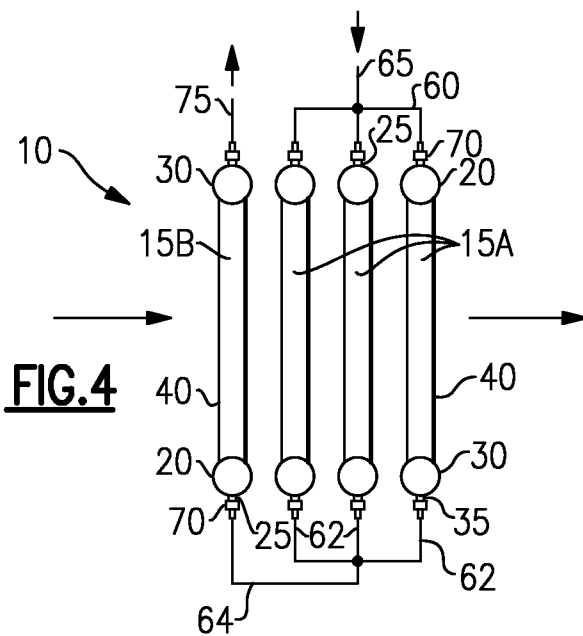


FIG.4

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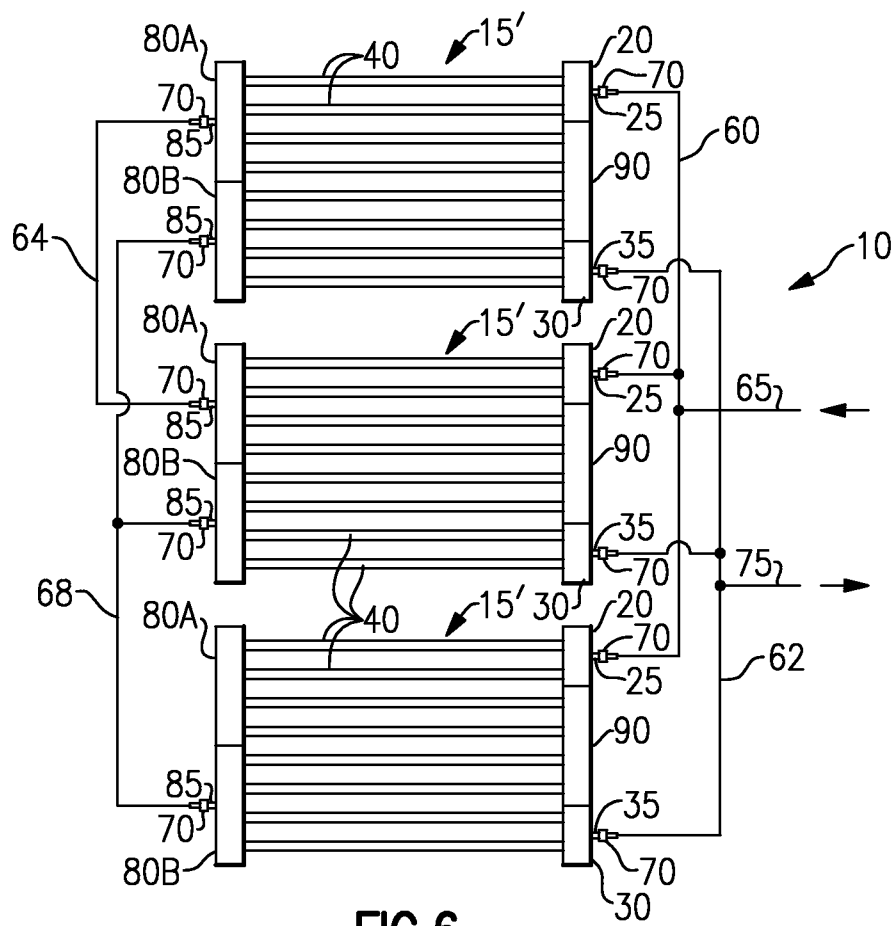


FIG. 6

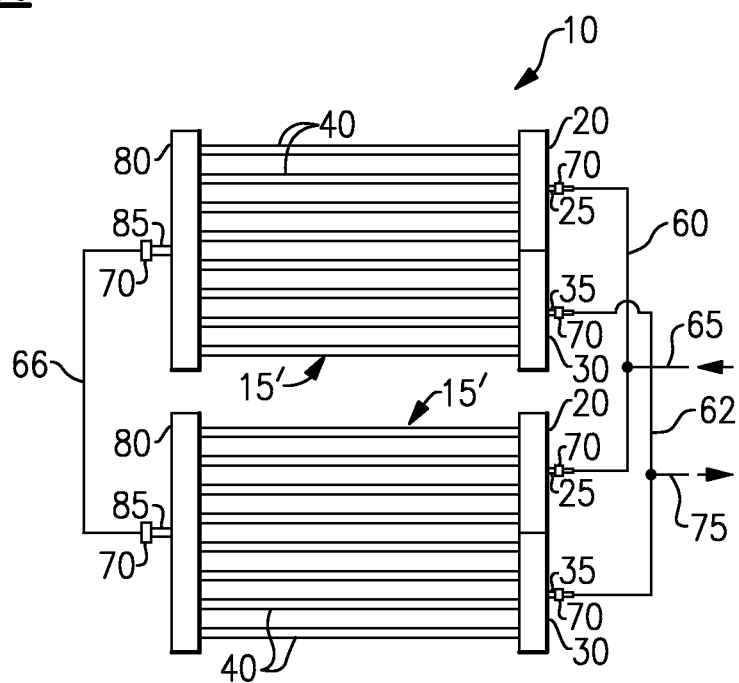
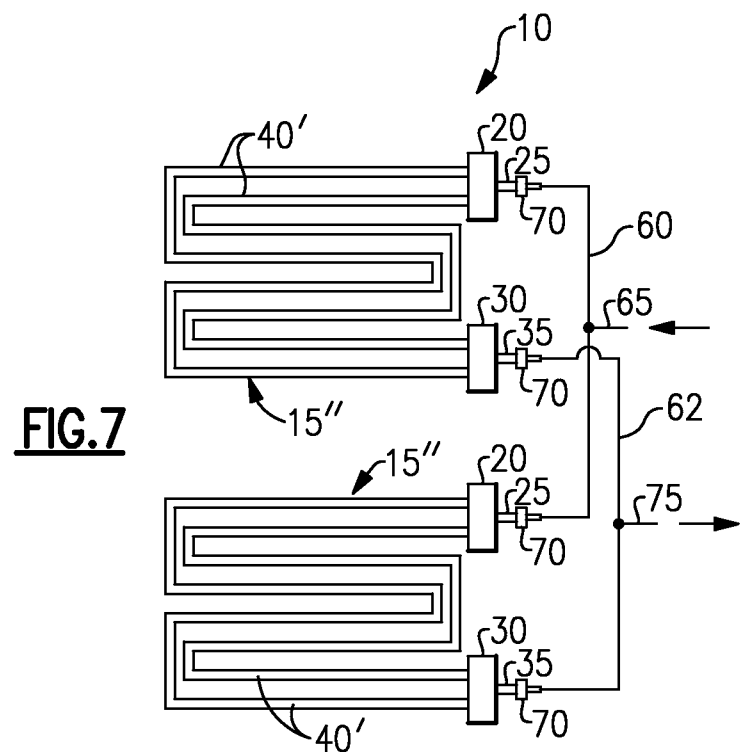
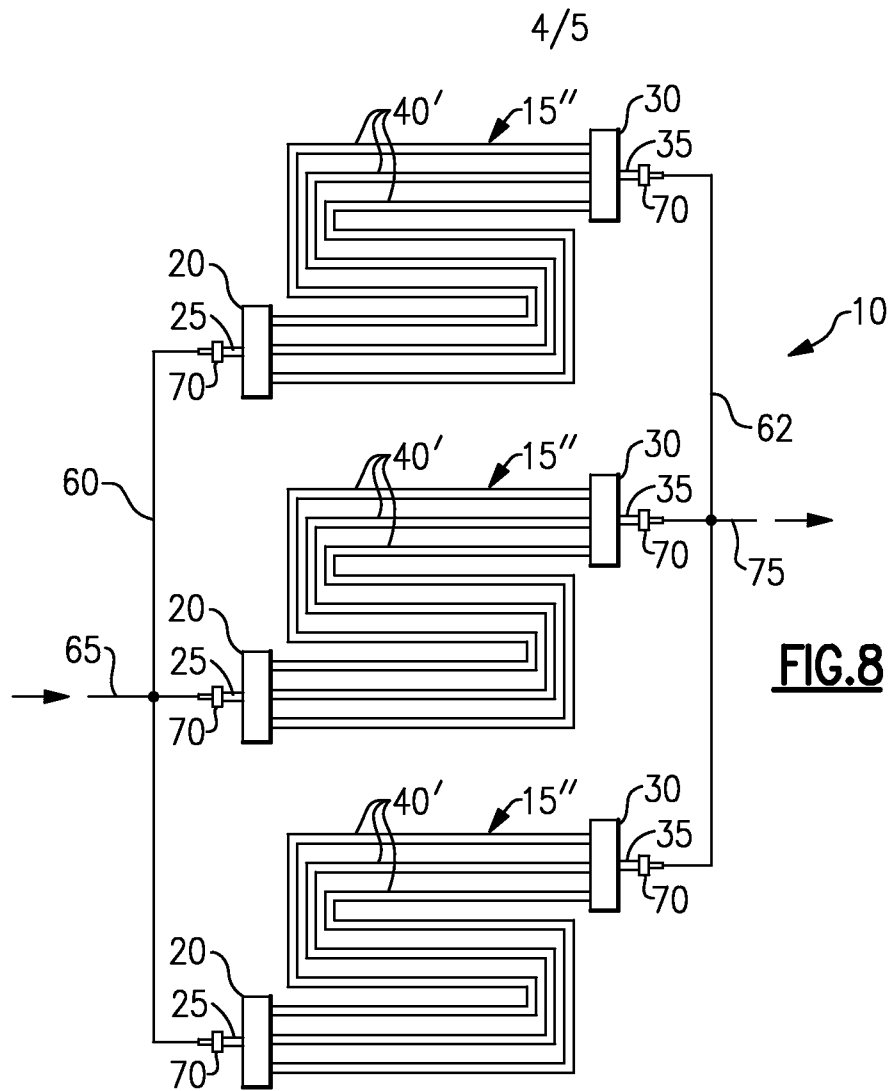


FIG. 5



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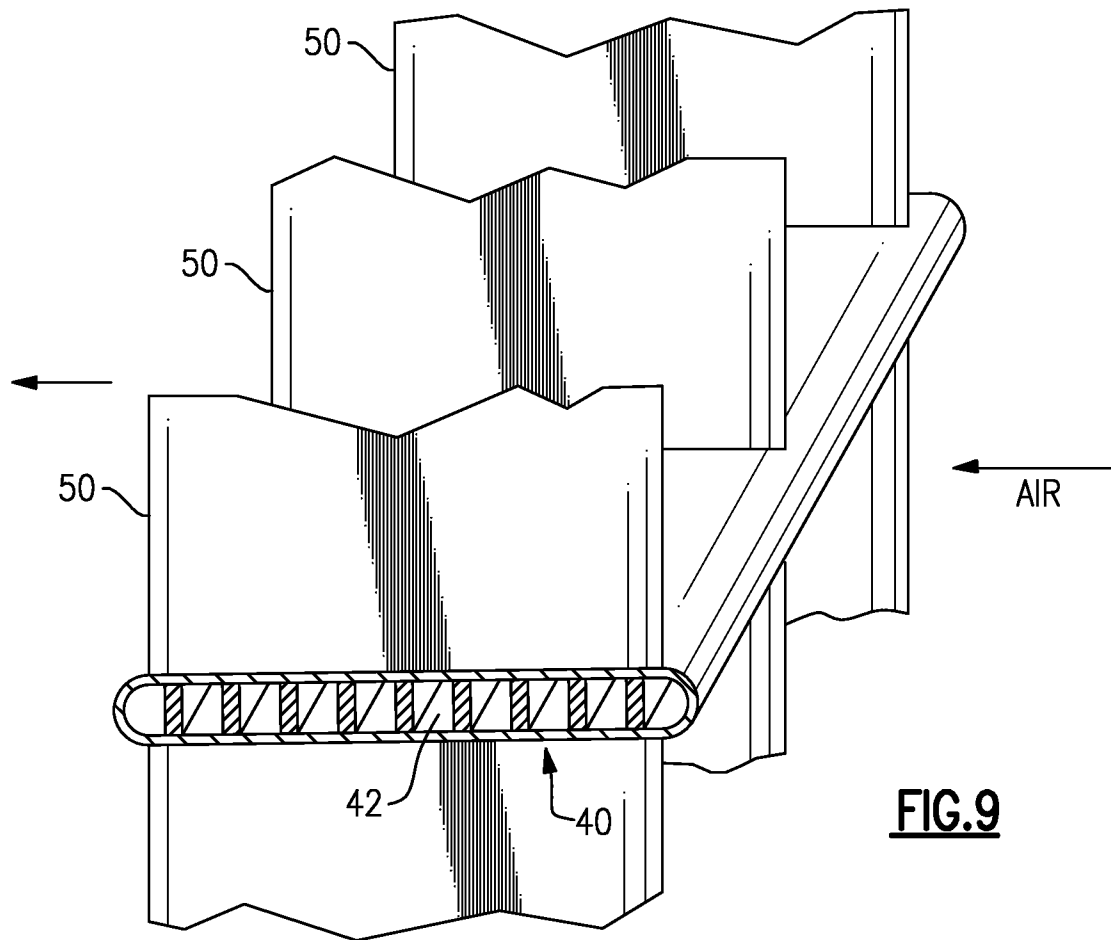


FIG. 9

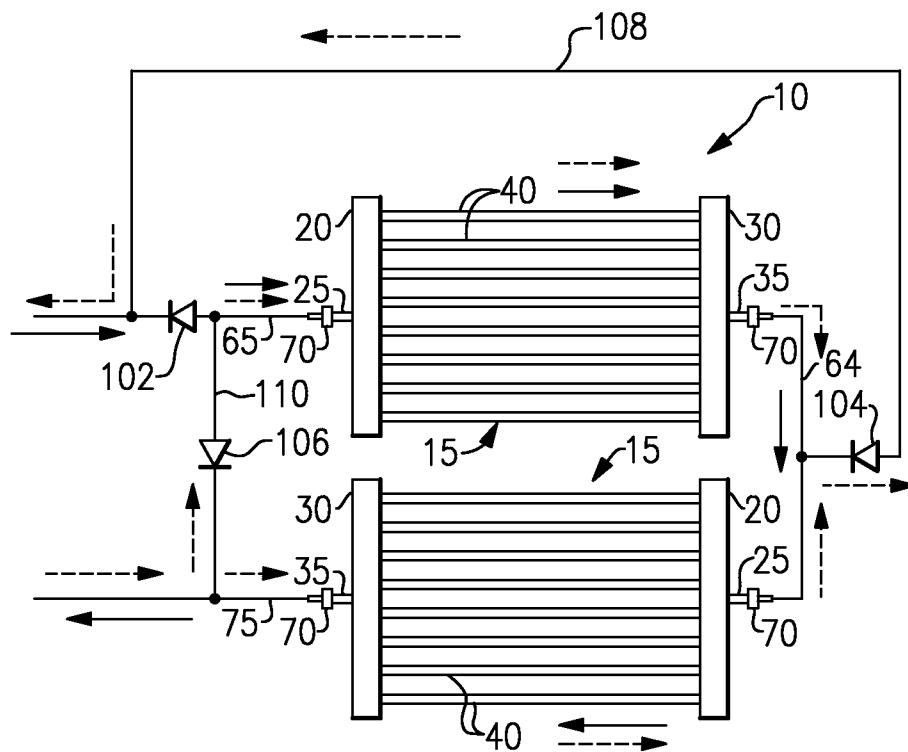


FIG. 10