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(54) HEAT EXCHANGER FOR PROVIDING SUPERCRITICAL COOLING OF A WORKING FLUID IN A TRANSCRITICAL COOLING CYCLE

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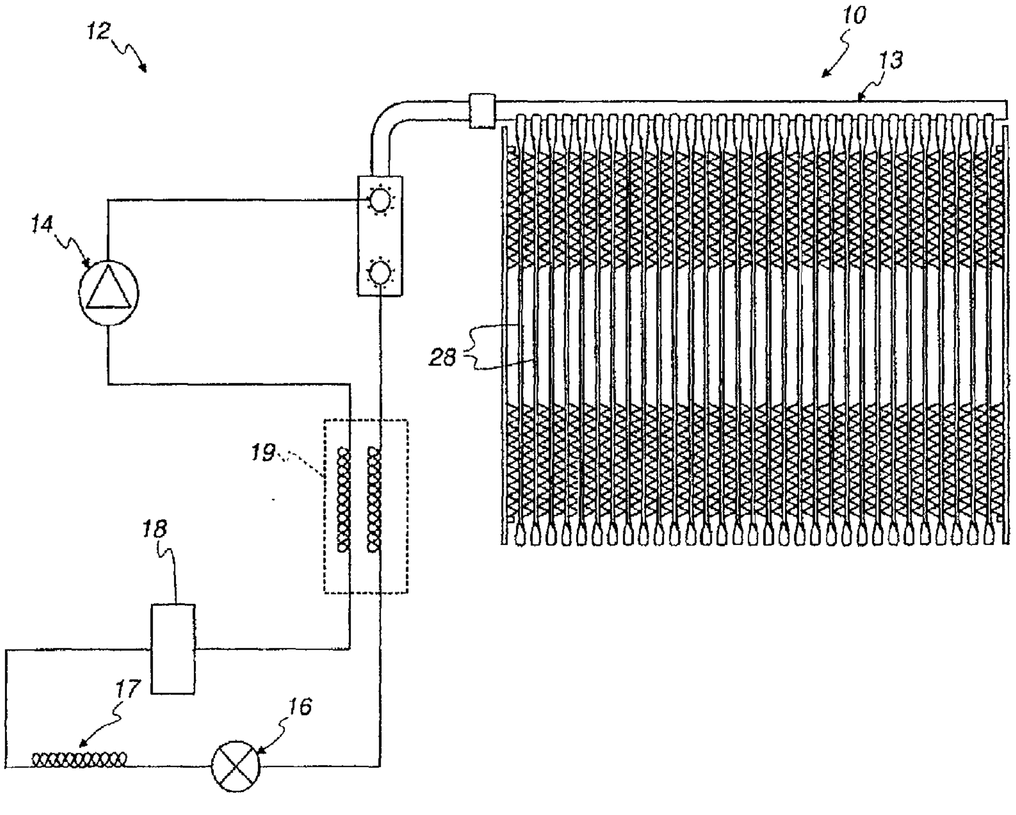
(57) ABSTRACT

A heat exchanger (**10**) preferably provides supercritical cooling to the refrigerant of a transcritical cooling system (**12**). The heat exchanger (**10**) includes a pair of elongated headers (**20, 22**) having longitudinal axes (**24, 26**) disposed substantially parallel to each other, a plurality of elongated tubes (**28**) spaced in side-by-side relation along the longitudinal axes (**24, 26**) of the headers (**20, 22**), and serpentine fins (**30**) extending between adjacent pairs of the tubes. Each of the tubes (**28**) has a first end (**31**) connected to the header (**20**) and a second end (**32**) connected to the other header (**22**) to the headers (**20, 22**). Each of the tubes (**28**) is folded upon itself to define at least two parallel legs (**36**) of the tubes (**28**) so that the refrigerant flows serially through at least two parallel fluid passes (**38**) from the header (**20**) to the header (**22**) Each of the tubes (**28**) has a flattened cross-section, and the parallel legs (**36**) of each of the tubes (**28**) are preferably spaced from each other, with the major dimension D of each of the parallel legs lying in a common plane. Preferably, each of the serpentine fins (**30**) has a transverse width W extending across the parallel legs (**36**) of the adjacent tubes (**28**). Each of the fins (**30**) includes a plurality of alternating tabs (**40**) and elongated separations (**42**) extending parallel to the parallel legs (**36**) and located between the parallel legs (**36**) of the adjacent tubes (**28**) to divide the width W of each fin (**30**) into two or more discrete fin elements (**44**) that are connected to each other by the tabs (**40**). Each of the fin elements (**44**) corresponds to and extends along one of the parallel legs (**36**) of each of the adjacent tubes (**28**).



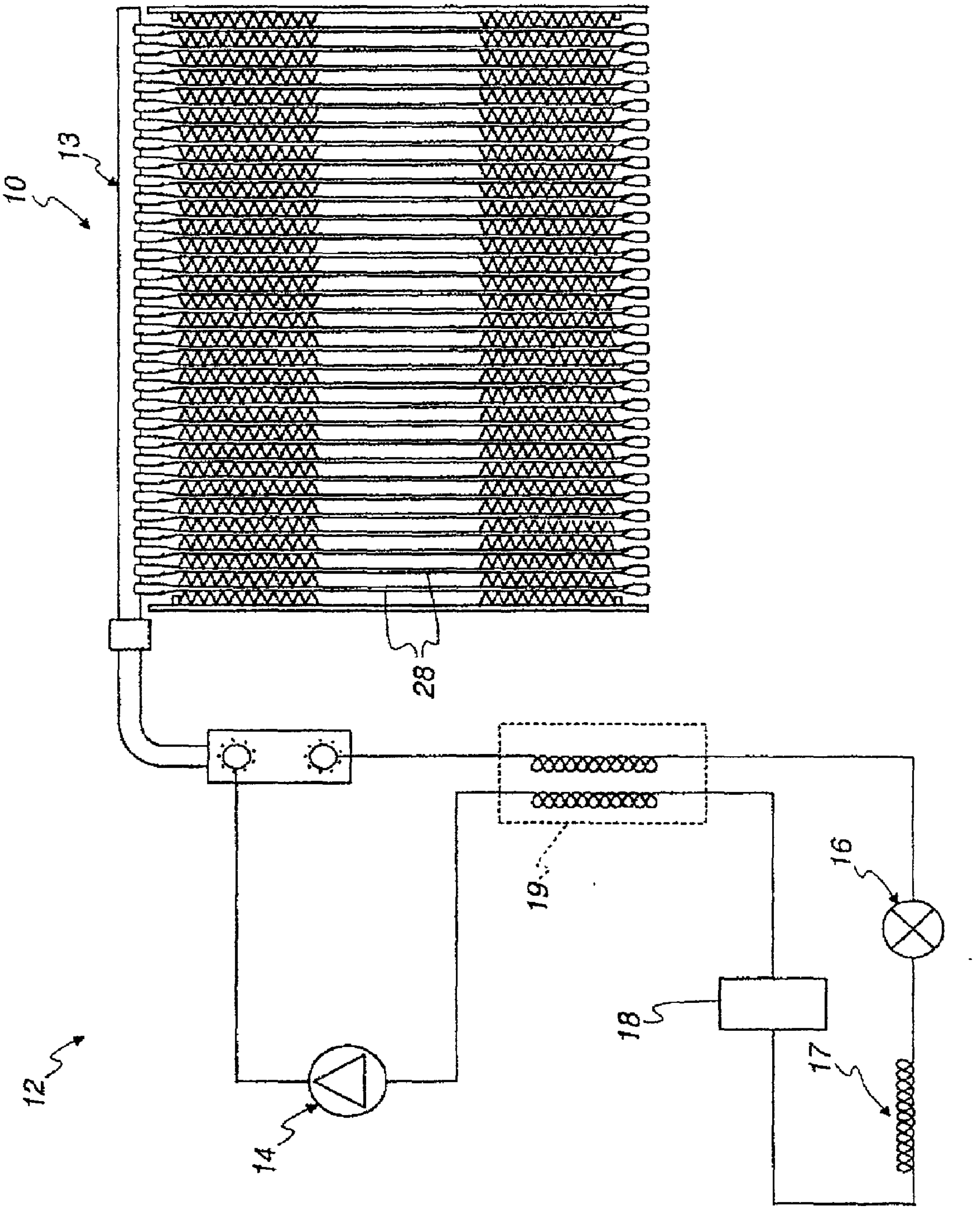


Fig. 1

Fig. 2

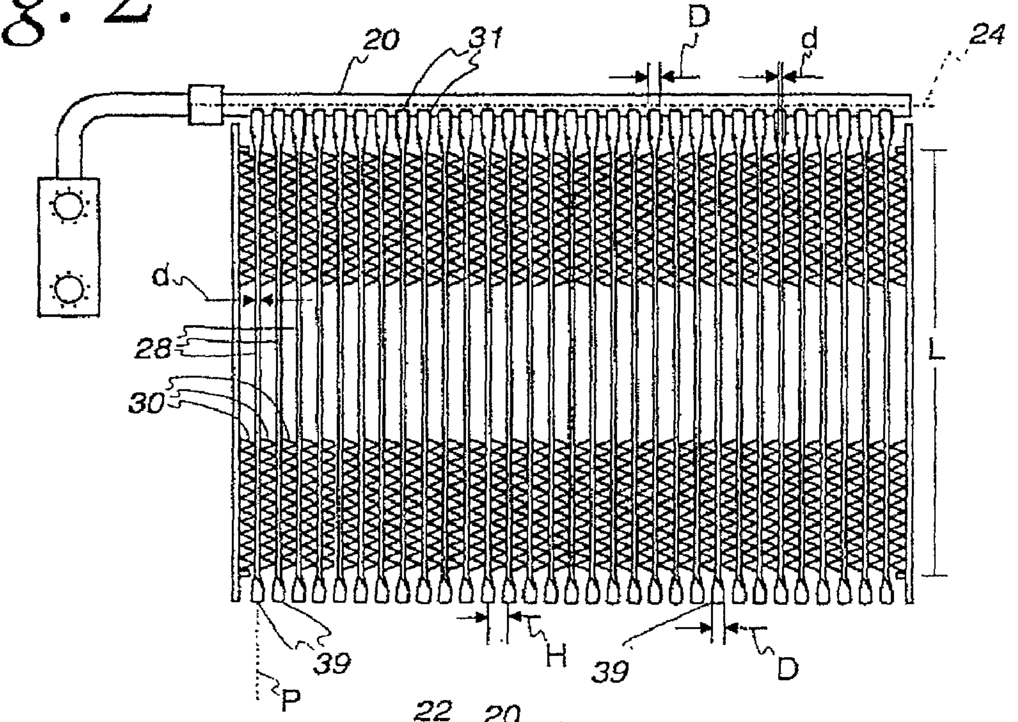


Fig. 3

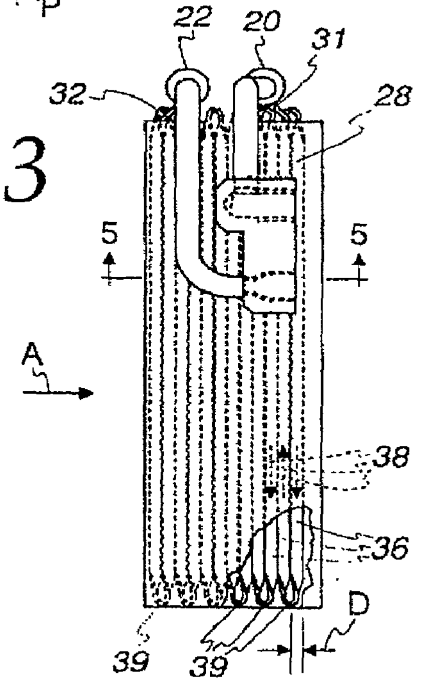


Fig. 4

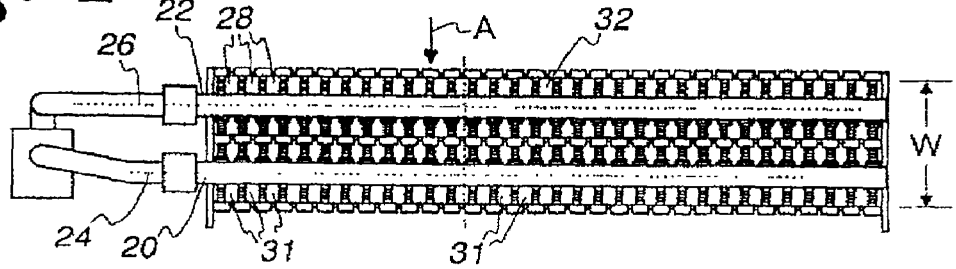


Fig. 5

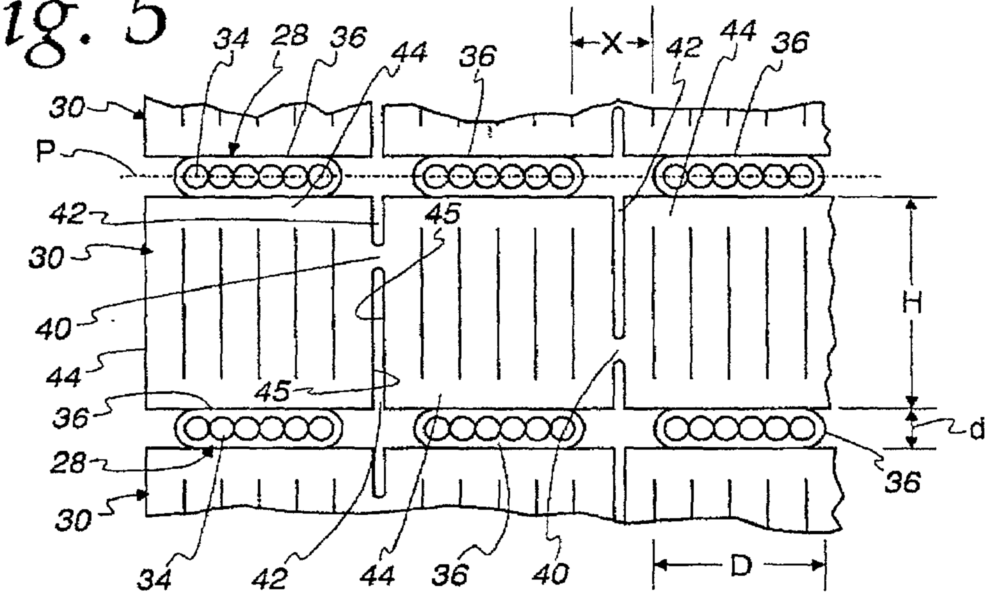


Fig. 6

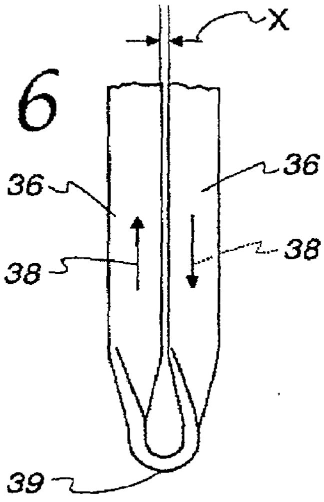
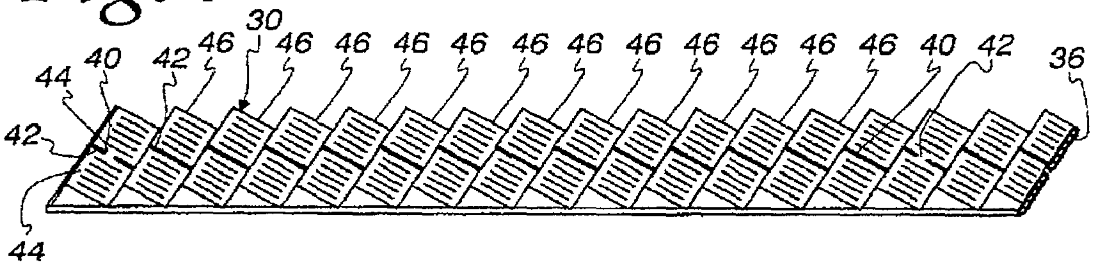


Fig. 7



HEAT EXCHANGER FOR PROVIDING SUPERCRITICAL COOLING OF A WORKING FLUID IN A TRANSCRITICAL COOLING CYCLE

FIELD OF THE INVENTION

[0001] This invention relates to heat exchangers, and more particularly, to heat exchangers that provide supercritical cooling of a working fluid in a transcritical cooling cycle.

BACKGROUND OF THE INVENTION

[0002] One common form of a heat exchanger includes a so called "core" made up of tubes and interconnecting fins. One fluid is passed through the tubes of the core while a second fluid is passed through the core itself in the spaces between the fins and tubes. Typically, the opposite ends of the tubes are connected to a pair of parallel manifolds or "tanks", with one of the manifolds being an inlet manifold and the other manifold being an outlet manifold which direct one of the fluids into and out of the tubes, respectively.

[0003] Heat exchangers of this general type are used for a large variety of purposes, such as radiators, condensers, evaporators, charge air coolers, oil coolers, etc., all of which may be utilized in a vehicle. One common form of this type of heat exchanger is known as a parallel flow heat exchanger wherein flat, multi-port tubes direct a refrigerant through the heat exchanger. Typically, the flat tubes are straight and the manifolds are spaced on opposite sides of the heat exchanger to receive the opposite ends of the tubes. However, it is known to bend the flat tubes so that each tube is shaped as a so called "hair pin" tube having two parallel legs, with the inlet and outlet manifold positioned next to each other to receive the ends of the tubes. One such construction is shown in U.S. Pat. No. 5,531,268 issued to Hoshino et al. While the construction shown in the U.S. Pat. No. 5,531,268 patent may be suitable for its intended purpose, there is always room for improvement. Further, the construction may not be suitable or optimum for use in some air conditioning systems that rely on a higher operating pressure, such as a transcritical cooling cycle that requires a gas cooler for providing supercritical cooling of a refrigerant such as carbon dioxide, (CO_2).

[0004] Increasing environmental concerns over the use of many conventional refrigerants such as CFC12 and, to a lesser extent, HFC134a, has led to consideration of transcritical CO_2 systems, particularly for use in vehicular applications. For one, the CO_2 utilized as a refrigerant in such systems could be claimed from the atmosphere at the outset with the result that if it were to leak from the system back to the atmosphere, there would be no net increase in atmospheric CO_2 content. Moreover, while CO_2 is undesirable from the standpoint of a greenhouse effect, it does not affect the ozone layer and would not cause an increase in the greenhouse effect since there would be no net increase in the atmospheric CO_2 content as a result of leakage.

SUMMARY OF THE INVENTION

[0005] It is the principle object of the invention to provide a new and improved heat exchanger.

[0006] It is another object of the invention to provide an improved heat exchanger that is suitable for supercritical cooling of a working fluid in a transcritical cooling cycle.

[0007] An exemplary embodiment of the invention achieves at least some of the foregoing objects in a heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle. The heat exchanger includes a pair of elongated headers having longitudinal axis disposed substantially parallel to each other, a plurality of elongated tubes spaced in side by side relation along the longitudinal axis of the headers, with each of the tubes being folded upon itself to define at least two parallel legs of the tube so that the working fluid flows serially through at least two parallel passes from one of the headers to the other, and serpentine fins extending between adjacent pairs of the tubes, with each of the fins having a length extending parallel to the parallel legs of the adjacent tubes. Each of the tubes has a flat cross-section with a major dimension and a minor dimension. The major dimensions of the parallel legs of each of the tubes lie in a common plane that is substantially transverse to the longitudinal axes of the headers. Each of the tubes has a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers.

[0008] In one form, each of the serpentine fins has a transverse width extending across the parallel legs of the adjacent tubes. Each of the fins includes a plurality of alternating tabs and elongated separations extending parallel to the parallel legs, with the tabs and separations located between the parallel legs of the adjacent tubes to divide the width of each fin into a plurality of discrete fin elements that are connected to each other by the tabs. Each of the fin elements corresponds to and extends along one of the parallel legs of each of the adjacent tubes.

[0009] In one form, the parallel legs of each of the tubes are spaced from each other.

[0010] In one form, each of the tubes is folded upon itself at least twice to define at least three parallel legs of the tube so that the working fluid flows serially through at least three parallel fluid passes from one of the headers to the other.

[0011] In one form, each of the tubes is a multi-port tube with a hydraulic diameter in the range of 0.015 inch to 0.040 inch.

[0012] In one form, the major dimension of each of the tubes is no greater than 0.500 inch and the minor dimension is no greater than 0.100 inch.

[0013] In one form, each of the fins has a fin height extending from one of the tubes to an adjacent one of the tubes, parallel to the longitudinal axes of the headers, and the major dimension of the tubes is no greater than the fin height.

[0014] In one form, the major dimensions of the tubes extend parallel to the longitudinal axes of the headers at the location where the tube end is connected to the header.

[0015] Other objects and advantages will become apparent from the following specification taken in connection with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

[0016] **FIG. 1** is a somewhat diagrammatic elevation view of a cooling system including a heat exchanger embodying the present invention;

[**0017**] **FIG. 2** is an elevation view of the heat exchanger shown in **FIG. 1**;

[**0018**] **FIG. 3** is a side view of the heat exchanger shown in **FIG. 2**;

[**0019**] **FIG. 4** is a top view of the heat exchanger shown in **FIG. 2**;

[**0020**] **FIG. 5** is an enlarged, partial section view taken along line **5-5** in **FIG. 3**;

[**0021**] **FIG. 6** is an enlarged, partial view of a tube employed in the heat exchanger shown in FIGS. **1-5**; and

[**0022**] **FIG. 7** is a perspective view showing a tube and a fin utilized in a heat exchanger embodying the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[**0023**] Referring to **FIG. 1, a** heat exchanger **10** embodying the present invention is shown in connection with a basic cooling system **12** that operates a transcritical cooling cycle. The heat exchanger **10** is shown in the form of a gas cooler **13** that provides supercritical cooling to the working fluid or refrigerant, such as CO_2, of the cooling system **12** by rejecting heat to a medium, such as an air flow A, on the fin side of the heat exchanger **10**. The cooling system **12** includes the heat exchanger **10**, a compressor **14**, that compresses gaseous phase refrigerants to a supercritical pressure for delivery to the heat exchanger **10**, an expansion device **16**, that reduces the pressure in the refrigerant received from the heat exchanger **10** so at least some of the refrigerant enters the liquid phase, an evaporator **17** that transfers heat from one medium into the refrigerant to change the refrigerant from the liquid phase to the gaseous phase, an accumulator **18** (optional), and a suction line heat exchanger **19** that transfers heat from the refrigerant exiting the heat exchanger **10** into the refrigerant exiting the evaporator **17**, or accumulator **18** if used. It should be understood that the heat exchanger **10** may find use in other types of cooling systems, and in other configurations of cooling systems that perform a transcritical cooling cycle, and is not limited to use with the specific cooling system shown in **FIG. 1** unless specifically recited in the claims. Further, while the disclosed heat exchanger **10** can provide distinct advantages when used as a gas cooler **13**, it may also prove advantageous when used for other purposes, such as a condenser or an evaporator, regardless of whether it is used in connection with a transcritical cooling cycle.

[**0024**] With reference to FIGS. **2-4**, the heat exchanger **10** includes a pair of elongated tubular headers **20** and **22** having longitudinal axes **24** and **26**, respectively, disposed substantially parallel to each other; a plurality of elongated tubes **28** spaced in side-by-side relations along the longitudinal axes **24**, **26** of the headers **20**, **22**; and serpentine fins **30** extending between adjacent pairs of the tubes **28**. It should be understood that in the illustrated embodiment, each fin **30** extends over a length L of the tubes **28**, but the middle portions of the lengths are not shown in **FIG. 2** for convenience of illustration. Preferably, the fins **30** are louvered. As seen in **FIG. 3**, each of the tubes **28** has a first end **31** connected to the header **20** and a second end **32** connected to the header **22** to transfer the refrigerant between the headers **20**, **22**.

[**0025**] Each of the tubes **28** has a flattened cross-section with a major dimension D and a minor dimension d, as best seen in **FIG. 5**. Each of the tubes **28** is preferably a multi-port tube and, in highly preferred embodiments, a multi-port tube having a hydraulic diameter in the range of 0.015 inch to 0.045 inch. In this regard, it should be understood that while **FIG. 5** shows six ports **34**, it may be beneficial in some applications to include more than, or less than, six ports **34** in each of the multi-port tubes **28**. For example, in one preferred embodiment each of the tubes has four ports **34**. In one preferred embodiment, the tubes are configured to withstand a burst pressure of at least 6500 PSI, at 70° F. ambient, such as may be required for operation as a gas cooler in a transcritical CO_2 cooling system.

[**0026**] Preferably, the major dimension D of each of the tubes **28** is nominally no greater than 0.500 inch and the minor dimension d is nominally no greater than 0.100 inch, while in some highly preferred embodiments the minor dimension d is nominally no greater than 0.060 inch and the major dimension D is nominally no greater than 0.320 inch. In this regard, reducing the major dimension D can offer a number of advantages. For example, because each of the tubes **28** includes at least two parallel legs **36**, the depth of the heat exchanger **10** becomes highly dependent upon the size of the major dimension D and will be reduced with the reduction in the major dimension D. Further, the diameter of the headers **20**, **22** can be reduced in a construction where the major dimension D of the tube ends **31**, **32** extends transverse to the longitudinal axes **24**, **26** of the headers **20**, **22** at the locations where the ends **31**, **32** are connected to the headers **20**, **22**, rather than the parallel construction shown in FIGS. **1-4**. Additionally, the length of the headers **20**, **22**, can be reduced in a construction wherein the major dimension D of the tube ends **31**, **32** extend parallel to the longitudinal axes **24**, **26** of the headers **20**, **22**, such as shown in FIGS. **1-4**. Finally, a reduction in the major dimension D can allow for a reduction in the fin height in some preferred embodiments. However, it should be understood that larger fin heights may offer advantages with respect to air side efficiency.

[**0027**] As best seen in **FIGS. 3**, **4** and **6**, each of the tubes **28** is folded upon itself to define at least two parallel legs **36** of the tube **28** so that the refrigerant flows serially through at least two parallel fluid passes **38** from the header **20** to the header **22**. In this regard, it is preferred that the inlet and outlet headers **20**, **22** be selected so that the heat exchanger **10** operates in a cross-counterflow configuration relative to the fluid flow on the fin side of the heat exchanger **10** when operating as a gas cooler. Each pair of the parallel legs is joined by a fold **39** that is twisted 90° relative to the legs **36** at the location of the fold **39** so that the major dimension D extends parallel to the axes **26**, **24** at the location of the fold **39**, rather than transverse. Preferably the fold **39** is formed by first twisting the legs **36** 90° relative to the portion of the tube **28** at the location of the fold **39**, and then bending the tube through approximately 180° at the location of the fold **39** to form the fold **39**. In this regard, it should be understood that the 90° twist of each of the legs **36** relative to the fold **39** can be in the same direction as shown in **FIGS. 3 and 6**, or in opposite, directions, depending upon which configuration offers the most advantage for a particular application of the heat exchanger **10**. As best seen in **FIG. 6**, the parallel legs **36** of each of the tubes **28** are preferably spaced from each other by a distance X, with the major dimension D of each of the parallel legs **36** lying in a common plane, illustrated by dashed line P in **FIGS. 2 and 5**, that is substantially transverse to the longitudinal axes **24**, **26** of the headers **20**, **22**. This allows the major dimension D to extend parallel to the direction of the flow of the medium through the fins **30**. The spacing X reduces heat conduction from one leg **36** to the other, which can be advantageous when the heat exchanger **10** is providing supercritical cooling because the temperature of the refrigerant can vary substantially as it flows through the tube **28** from one header **20** to the other header **22**. Preferably, the distance X is sufficient to minimize or prevent the closing of the space between adjacent parallel legs **36** by braze material during brazing of the heat exchanger **10**, but not so large so as to unduly increase the depth of the heat exchanger **10**. While it is preferred that the adjacent parallel legs **36** of each tube **28** be spaced from each other, in some applications this spacing may not be required and/or desirable.

[**0028**] As seen in **FIGS. 1 and 5**, each of the fins **30** has a fin height H equal to the spacing between adjacent tubes **28**, i.e. a fin height H extending from one of the tubes **28** to an adjacent tube **28** parallel to the longitudinal axes **24**, **26** of the headers **20**, **22**. Preferably, the major dimension D of the tubes **28** is no greater than the fin height H. This allows a construction wherein each of the tube ends **31**, **32** can be twisted 90° relative to the parallel legs **36** from which they extend so that the major dimension D of the end **31**, **32** extends parallel to the longitudinal axes **24**, **26** of the headers **20**, **22** at the location where the tube ends **31** and **32** are connected to the headers **20** and **22**, as seen in **FIG. 2**. This can be important in high pressure applications, such as gas coolers used in transcritical refrigeration systems, where it is desirable that the diameter of the headers **20**, **22** be as small as possible. It is conceivable, even likely, in such constructions that the major dimension D will be greater than the inner diameter of either of the headers **20**, **22**. By allowing the major dimension D to extend parallel to the longitudinal axis **24**, **26** of the headers **20**, **22** where the tube ends **31**, **32** are connected to the headers **20**, **22**, the major dimension D of each of the tubes **28** can be greater than the inner diameter of either of the headers **20**, **22**. While it is preferred that the major dimension D of the tube ends **31**, **32** extend parallel to the longitudinal axes **24**, **26** of the headers **20**, **22** at the location where the tube ends **31**, **32** are connected to the headers **20**, **22**, other orientations of the major dimension D at these locations may be advantageous in some applications. For example, it may be advantageous in some applications for the major dimension D of the tube ends **31**, **32** to extend transverse to the longitudinal axes **24**, **26** at the location where the tube ends **31**, **32** are connected to the headers **20**, **22**.

[**0029**] As previously discussed, each of the serpentine fins **30** has a length L extending parallel to the parallel legs **36** of the adjacent tubes **28** and, as best seen in **FIG. 4, a** transverse width W extending across the parallel legs **36** of the adjacent tubes **28**. For purposes of illustration, **FIG. 5** shows three legs **36** of the tubes **28** and **FIG. 7** shows a fin **30** for use with a heat exchanger construction **10** wherein each of the tubes **28** has only two parallel legs **36**. With reference to **FIG. 7**, each of the fins **30** includes a plurality of alternating tabs **40** and elongated separations **42** extending parallel to the parallel legs **36** and located between the parallel legs **36** of the adjacent tubes **28** to divide the width W of each fin **30** into two or more discrete fin strips or elements **44** that are connected to each other by the tabs **40**. Each of the fin elements **44** corresponds to and extends along one of the parallel legs **36** of each of the adjacent tubes **28**. The separations **42** are generally straight line and have opposed edges **45** that face one another and are generally transverse to the direction of the medium flow through the fins **30**. While **FIG. 7** illustrates the fin **30** for tubes **28** having two parallel legs **36**, it should be understood that the above construction including the tabs **40**, separations **42** and fin elements **44** is utilized in constructions of the heat exchanger **10** having more than two parallel legs **36** in each of the tubes **28**, such as the constructions shown in FIGS. 2-5. In such constructions, each of the fins **30** preferably extends across all of the parallel legs **36** with a fin element **44** corresponding to and extending along each of the parallel legs **36** of each of the adjacent tubes **28**, and the tabs **40** and separations **42** provided between each of the fin elements **44**.

[**0030**] The alternating tabs **40** in each of the fins **30** serve to restrict movement of the fin elements **44** relative to each other so that each fin **30** remains a unitary component during the assembly of the heat exchanger **10** and, furthermore, to better maintain the fin elements **44** in alignment with each other to minimize the pressure drop on the fin side of the heat exchanger. The purpose of the elongated separations **42** is to minimize the heat conduction from each of the parallel legs **36** to any adjacent parallel leg **36** of each tube **28** by interrupting, and thus minimizing, the heat conduction between the fin elements **44** associated with each of the parallel legs **36**. This is desirable in applications, such as the gas cooler **13** of FIGS. 2-4, where the working fluid temperature entering the heat exchanger **10** is significantly different from the desired temperature for the working fluid leaving the heat exchanger **10**. It has been calculated that for a fin **30** with only 10% of its height unlouvered (typical in a louvered fin), as much as 40% of the total heat transfer between the parallel legs **36** can be conducted through the fins, and hence not rejected into the air. In some situations, conduction of the heat received from the fin **30** on the hot side of the heat exchanger **10** can actually make the fin **30** on the cold side of the heat exchanger **10** hotter than the working fluid flowing through the tubes **28** on the cold side, which leads to the undesirable situation of transferring heat back into the working fluid prior to the working fluid leaving the heat exchanger **10**. Thus, it is desirable for each of the elongated separations **42** to extend uninterrupted as far as possible along the length of the fin **30** and for the number and size of the tabs **40** to be minimized to that which is required to prevent each of the fin elements **44** from separating during assembly and to maintain an acceptable degree of alignment between the fin elements **44** of each of the fins **30** during assembly.

[**0031**] From the foregoing, It should be understood that a number of configurations are possible for the tabs **40** and the elongated separations **42**. For example, in one embodiment of a fin **30** made of aluminum, with the fin **30** in an unfolded state, each of the tabs **40** extends approximately 0.020 inch along the length of the fin **30** and each of the elongated separations **42** of a fin **30** made of aluminum extends approximately 8.0 inches along the length of the unfolded fin **30**. In one preferred embodiment of the fin **30**, the tabs **40** and the separations **44** have lengths extending parallel with the length of the fin **30** in the unfolded state and the ratio of the length of the separations **42** to the length of the tabs **40** is in the range of 200 to 600. In another example, such as shown in **FIG. 7**, each of the elongated separations **42** extends uninterrupted from one of the tabs **40** over 10 to 14 of the folds **46** to the next tab **40** with the fin **30** in the folded condition.

[**0032**] While the tabs **40** and the separations **42** can be formed in a number of ways, it is preferred that the separations **42** be formed as cuts or slits in the fin material that do not require removal of fin material during formation in the fin **30**. One way of achieving such slits or cuts is to use a splitter disk in the fin roll die to create a simple cut in the fin **30** as the fin **30** is formed from a strip of sheet material. The split could be eliminated for a small portion of the disk in every revolution to form the tabs **40** to ensure that each fin element **44** stays attached to the adjoining fin element **44** of the fin **30**. This provides a physical cut or slit in the fin **30**, with no loss of fin surface. In one such construction the edges **45** are virtually, but not quite, in abutment with each other. One concern is that the fin elements **44** might braze together during the brazing process. One approach to minimize this concern is to locate the braze material on the side walls of the tube legs **36** that abut the fins **30**, rather than cladding the braze material onto the fins **30**. Another approach to minimize this concern is to offset adjacent fin elements **44** of the fin **30** at locations remote from the tab **40**, which may allow for clad fins. Another approach would be to bend the edges **45** formed by the slits slightly apart, forming a very small louver, which may also allow for clad fins. Yet another approach is to coin each of the tab portions **40** to further separate the fin elements **44** from each other. Again, this last approach may allow for clad fins. While slits are preferred, in some applications it may be advantageous for the separations **42** to be formed as slots that do require removal of fin material when formed in the fins **30**. In this regard, it would probably be sufficient for the slots to have a width of a few thousands of an inch parallel to the width W of the fin **30**.

[**0033**] While it is preferred that the fins **30** include the tabs **40** and separations **44**, in some applications the tabs **40** and separations **42** may not be desirable and/or required.

[**0034**] It is preferred that the fins **30** be louvered, many forms of which are known. The exact configuration of the louvers will be highly dependent on the parameters of the particular application such as, for example, the fluid on the fin side of the heat exchanger **10**, the available pressure drop on the fin side of the heat exchanger **10**, the number of parallel legs **36** in each of the tubes **28**, and whether there is an odd or even number of parallel legs **36** in each of the tubes **28**.

[**0035**] It should be understood that when operating as a gas cooler **13** in the system **12**, the heat exchanger **10** will typically provide supercritical cooling of the refrigerant; however, there may be some conditions of operation wherein the ambient temperature is below the critical temperature, in which case the heat exchanger **10** will operate as a condenser that provides subcritical cooling for the refrigerant.

[**0036**] As best seen in **FIG. 3**, the illustrated heat exchanger **10** includes 12 parallel legs **36** for each of the tubes **28**. However, it should be understood that the optimum number of parallel legs for each application of the heat exchanger **10** will be highly dependent upon the specific parameters for the particular application such as, for example, the working fluid of the system **12**, the envelope and environment into which the heat exchanger **10** must be packaged, and the function of the heat exchanger, i.e., as a gas cooler, condenser, or evaporator for use in either an AC or heat pump system. For example, in some applications it may be desirable to only have two or three parallel legs **36** for each of the tubes **28**.

[**0037**] As another option, one or more baffles can be provided within either or both of the headers **20**, **22** to direct the refrigerant from the header **20** through a subset of the tubes **28** to the header **22** and then back through a different subset of the tubes **28** to the header **20** and so on for as many passes from one header to the other as may be needed to provide the performance dictated by each particular application.

[**0038**] In one preferred embodiment the headers **20**, **22**, tubes **28**, and fins **30** are all made of aluminum and brazed with an appropriate braze material. However, it should be understood that in some applications other suitable materials made be employed for these components as dictated by the parameters of the particular application.

[**0039**] It should also be understood that while the heat exchanger **10** illustrated in FIGS. **1-3** is shown so that the longitudinal axes **24**, **26** of the headers **20**, **22** extend in a horizontal direction, and the parallel legs **36** of the tubes **28** extend in a vertical direction, it may be desirable in some applications for a heat exchanger **10** to have a different orientation, such as, for an example, an orientation wherein the axes **24**, **26** extend in a vertical direction and the parallel legs **36** extend in a horizontal direction. Further, while the headers **20**, **22** of the heat exchanger **10** illustrated in FIGS. **1-3** are located on the same side of the heat exchanger **10**, it may be desirable in some applications for the headers **20**, **22** to be located on opposite sides of the heat exchanger **10**. A construction with the headers **20**, **22** on the same side of the heat exchanger will typically result in an even number of parallel legs **36** for each of the tubes **28**, while a construction with the headers **20**, **22** on opposite sides of the heat exchanger **10** will typically result in a odd number of parallel legs **36** for each of the tubes **28**. Of course, header plates fitted with tanks could be employed in lieu of the tubular headers **20**, **22** if desired for a particular application.

I claim:

1. A heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle, the heat exchanger comprising:

a pair of elongated headers having longitudinal axes disposed substantially parallel to each other;

a plurality of elongated tubes spaced in side by side relation along the longitudinal axes of the headers, each of the tubes having a flattened cross-section with a major dimension and a minor dimension, each of the tubes having a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers, each of the tubes being folded upon itself to define at least two parallel legs of the tube so that the working fluid flows serially through at least two parallel fluid passes from one of the headers to the other, the parallel legs of each of the tubes being spaced from each other with the major dimension of each of the parallel legs lying in a common plane that is substantially transverse to the longitudinal axes of the headers; and

serpentine fins extending between adjacent pairs of said tubes, each of the fins having a length extending parallel to the parallel legs of the adjacent tubes and a transverse width extending across the at least two parallel legs of the adjacent tubes, each of the fins including a plurality of alternating tabs and elongated separations extending parallel to the parallel legs, the tabs and separations located between the parallel legs of the adjacent tubes to divide the width of each fin into a plurality of discrete fin elements that are connected to each other by the tabs, each of the fin elements corresponding to and extending along one of the parallel legs of each of the adjacent tubes.

2. The heat exchanger of claim 1 wherein the major dimension of each of the tubes is no greater than 0.500 inch and the minor dimension is no greater than 0.100 inch.

3. The heat exchanger of claim 1 wherein the major dimension of each of the tubes is no greater than 0.320 inch and the minor dimension is no greater than 0.060 inch.

4. The heat exchanger of claim 1 wherein each of th e tubes is folded at least twice to define at least three parallel legs of the tube so that the working fluid flows serially through at least three parallel fluid passes from one of the headers to the other.

5. The heat exchanger of claim 1 wherein each of the fins have a fin height extending from one the tubes to an adjacent one of the tubes, parallel to the longitudinal axes of the headers, and the major dimension of the tubes is no greater than the fin height.

6. The heat exchanger of claim 1 wherein the major dimension of each of the tube ends extends parallel to the longitudinal axes of the headers at the location where the tube end is connected to the header.

7. The heat exchanger of claim 1 wherein said separations in said fins are slits that do not require removal of fin material when formed in the fins.

8. The heat exchanger of claim 1 wherein said separations in said fins are slots that do require removal of fin material when formed in the fins.

9. The heat exchanger of claim 1 wherein, for at least one of the fins in an unfolded state of the fin, said separations and said tabs have lengths extending parallel with the length of the fin, and the ratio of the lengths of the separations to the lengths of the tabs is in the range of 200 to 600.

10. The heat exchanger of claim 1 wherein at least one of the tubes is a multi-port tube having a hydraulic diameter in the range of 0.015 inch to 0.040 inch.

11. A heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle, the heat exchanger comprising:

a pair of elongated headers having longitudinal axes disposed substantially parallel to each other;

a plurality of elongated tubes spaced in side by side relation along the longitudinal axes of the headers, each of the tubes having a flattened cross-section with a major dimension and a minor dimension, each of the tubes having a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers, each of the tubes being folded upon itself to define at least two parallel legs of the tube so that the working fluid flows serially through at least two parallel fluid passes from one of the headers to the other, the parallel legs of each of the tubes having their major dimensions lying in a common plane that is substantially transverse to the longitudinal axes of the headers; and

serpentine fins extending between adjacent pairs of said tubes, each of the fins having a length extending parallel to the parallel legs of the adjacent tubes and a transverse width extending across the at least two parallel legs of the adjacent tubes, each of the fins including a plurality of alternating tabs and elongated separations extending parallel to the parallel legs, the tabs and separations located between the parallel legs of each of the adjacent tubes to divide the width of each fin into a plurality of discrete fin elements that are connected to each other by the tabs, each of the fin elements corresponding to and extending along one of the parallel legs of each of the adjacent tubes.

12. The heat exchanger of claim 11 wherein the major dimension of each of the tubes is no greater than 0.500 inch and the minor dimension is no greater than 0.100 inch.

13. The heat exchanger of claim 11 wherein the major dimension of each of the tubes is no greater than 0.320 inch and the minor dimension is no greater than 0.060 inch.

14. The heat exchanger of claim 11 wherein each of the tubes is folded at least twice to define at least three parallel legs of the tube so that the working fluid flows serially through at least three parallel fluid passes from one of the headers to the other.

15. The heat exchanger of claim 11 wherein the major dimension of each of the tube ends extends parallel to the longitudinal axes of the headers at the location where the tube end is connected to the header.

16. The heat exchanger of claim 11 wherein said separations in said fins are slits that do not require removal of fin material when formed in the fins.

17. The heat exchanger of claim 11 wherein, for at least one of the fins in an unfolded state of the fin, said separations and said tabs have lengths extending parallel with the length of the fin, and the ratio fo the lengths of the separations to the lengths of the tabs is in the range of 200 to 600.

18. A heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle, the heat exchanger comprising:

a pair of elongated headers having longitudinal axes disposed substantially parallel to each other;

a plurality of elongated tubes spaced in side by side relation along the longitudinal axes of the headers, each of the tubes having a flattened cross-section with a major dimension and a minor dimension, the major dimension of each of the tubes being no greater than 0.500 inch and the minor dimension being no greater than 0.100 inch, each of the tubes having a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers, each of the tubes being folded upon itself to define at least two parallel legs of the tube so that the working fluid flows serially through at least two parallel fluid passes from one of the headers to the other, the parallel legs of each of the tubes having their major dimensions lying in a common plane that is substantially transverse to the longitudinal axes of the headers; and serpentine fins extending between adjacent pairs of said tubes, each of the fins having a length extending parallel to the parallel legs of the adjacent tubes.

19. A heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle, the heat exchanger comprising:

a pair of elongated headers having longitudinal axes disposed substantially parallel to each other;

a plurality of elongated tubes spaced in side by side relation along the longitudinal axes of the headers, each of the tubes having a flattened cross-section with a major dimension and a minor dimension, each of the tubes having a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers, each of the tubes being folded upon itself at least twice to define at least three parallel legs of the tube so that the working fluid flows serially through at least three parallel fluid passes from one of the headers to the other, the parallel legs of each of the tubes having their major dimensions lying in a common plane that is substantially transverse to the longitudinal axes of the headers; and

serpentine fins extending between adjacent pairs of said tubes, each of the fins having a length extending parallel to the parallel legs of the adjacent tubes.

20. A heat exchanger for providing supercritical cooling of a working fluid in a transcritical cooling cycle, the heat exchanger comprising:

a pair of elongated headers having longitudinal axes disposed substantially parallel to each other;

a plurality of elongated tubes spaced in side by side relation along the longitudinal axes of the headers, each of the tubes having a flattened cross-section with a major dimension and a minor dimension, each of the tubes being a multi-port tube with a hydraulic diameter in the range of 0.015 inch to 0.040 inch, each of the tubes having a first end connected to one of the headers and a second end connected to the other header to transfer the working fluid between the headers, each of the tubes being folded upon itself to define at least two parallel legs of the tube so that the working fluid flows serially through at least two parallel fluid passes from one of the headers to the other, the parallel legs of each of the tubes having their major dimensions lying in a common plane that is substantially transverse to the longitudinal axes of the headers; and

serpentine fins extending between adjacent pairs of said tubes, each of the fins having a length extending parallel to the parallel legs of the adjacent tubes.

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