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(54) **HEAT EXCHANGER**

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F28D 7/10	(2006.01)
F28F 9/02	(2006.01)
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(58) **Field of Classification Search**

CPC . F28D 7/02; F28D 7/024; F28D 7/026; F28D 7/04

USPC 165/139, 160, 159, 163

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,768,222 A * 6/1930 Uhde F22G 1/005 165/163

2,468,903 A * 5/1949 Villiger F28D 7/1669 122/511

(Continued)

FOREIGN PATENT DOCUMENTS

GB 1163804 A 9/1969

OTHER PUBLICATIONS

Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, PCT/US2017/042828, Sep. 27, 2017.

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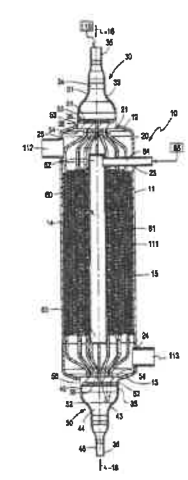
(57) **ABSTRACT**

A heat exchanger is described and which includes an exterior container having an internal cavity; a refrigerant distribution tube is positioned within the internal cavity and which is further coupled in fluid receiving relation relative to a first source of refrigerant; and a multiplicity of closely nested refrigerant tubes are located within the internal cavity and are further disposed in a closely spaced, radially outwardly oriented positions relative to the refrigerant distribution tube, and which additionally have a predetermined and similar length dimension, and individually form helical coils which have a given and similar length dimension, and a variable pitch, and which are further coupled to a second source of a refrigerant.

7 Claims, 4 Drawing Sheets



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F25B 39/04 (2006.01)
F28D 21/00 (2006.01)
F25B 7/00 (2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,332,478	A *	7/1967	Saunders	F24D 3/082 165/163
6,102,106	A	8/2000	Manning et al.	
6,679,083	B1 *	1/2004	Erickson	F25B 37/00 62/476
7,131,489	B2 *	11/2006	Gohna	F28D 7/1607 165/161
7,377,307	B1 *	5/2008	Ijiri	F28D 7/16 165/100
7,594,536	B2 *	9/2009	Sugihara	F28D 7/16 123/568.12
2003/0111209	A1 *	6/2003	Tsujita	F28D 7/1653 165/51
2008/0149317	A1	6/2008	Baker	
2013/0139541	A1 *	6/2013	Seybold	F28D 7/10 62/498
2017/0000653	A9	1/2017	Kameda et al.	

* cited by examiner

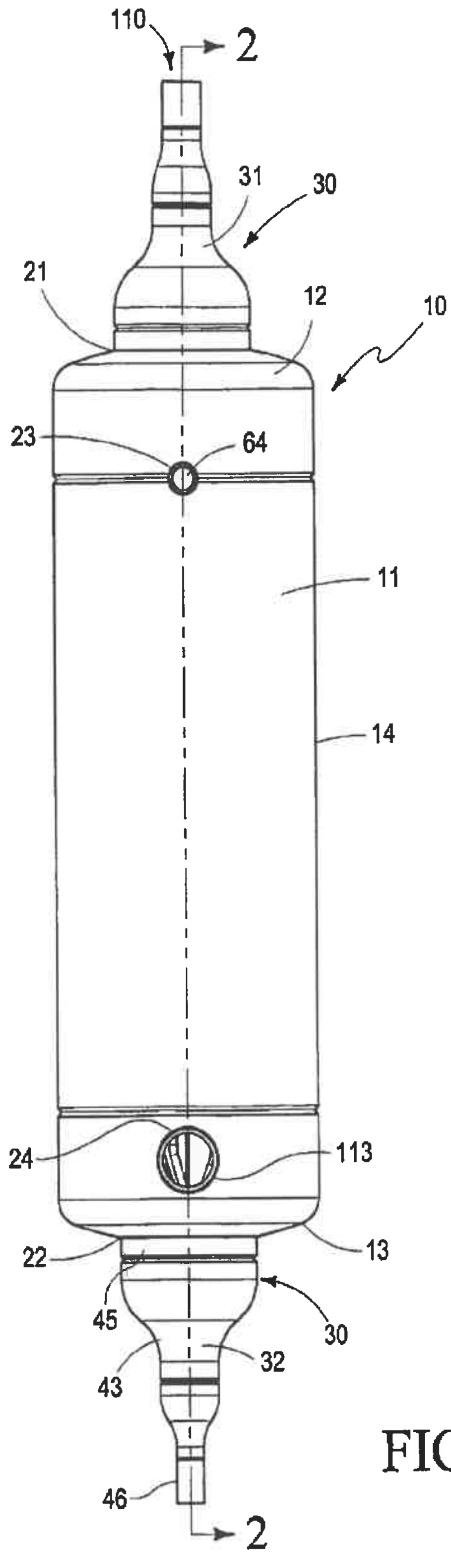

FIG. 1

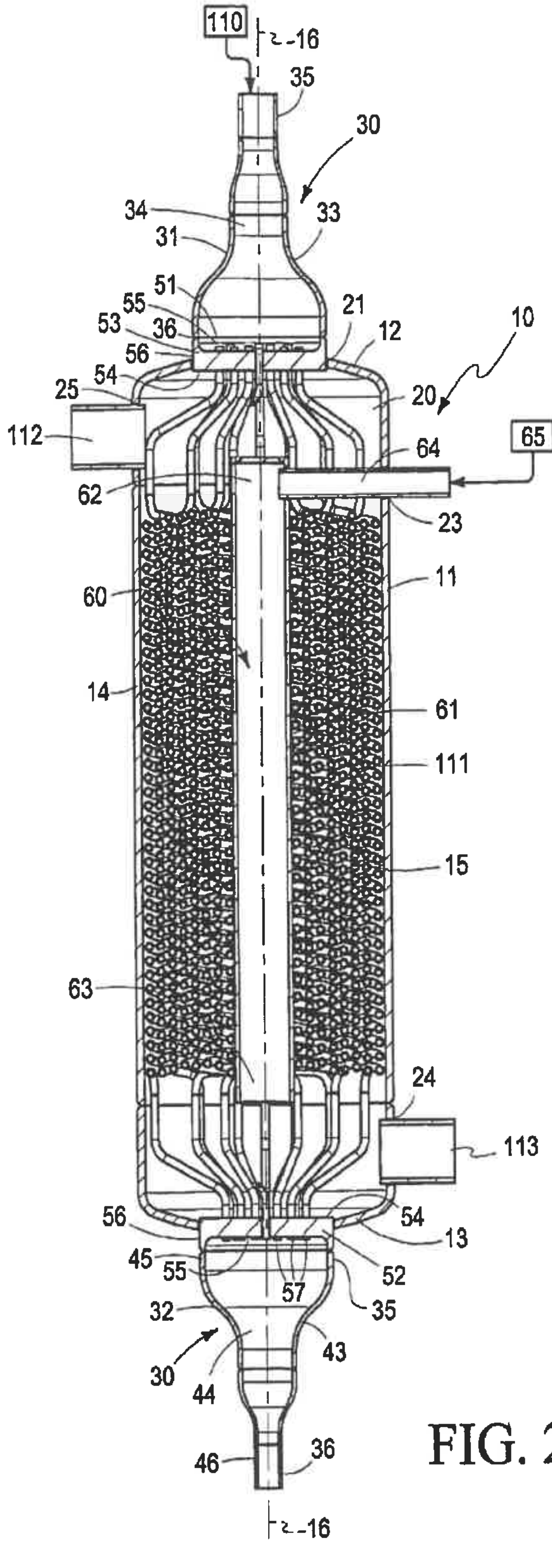
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FIG. 2

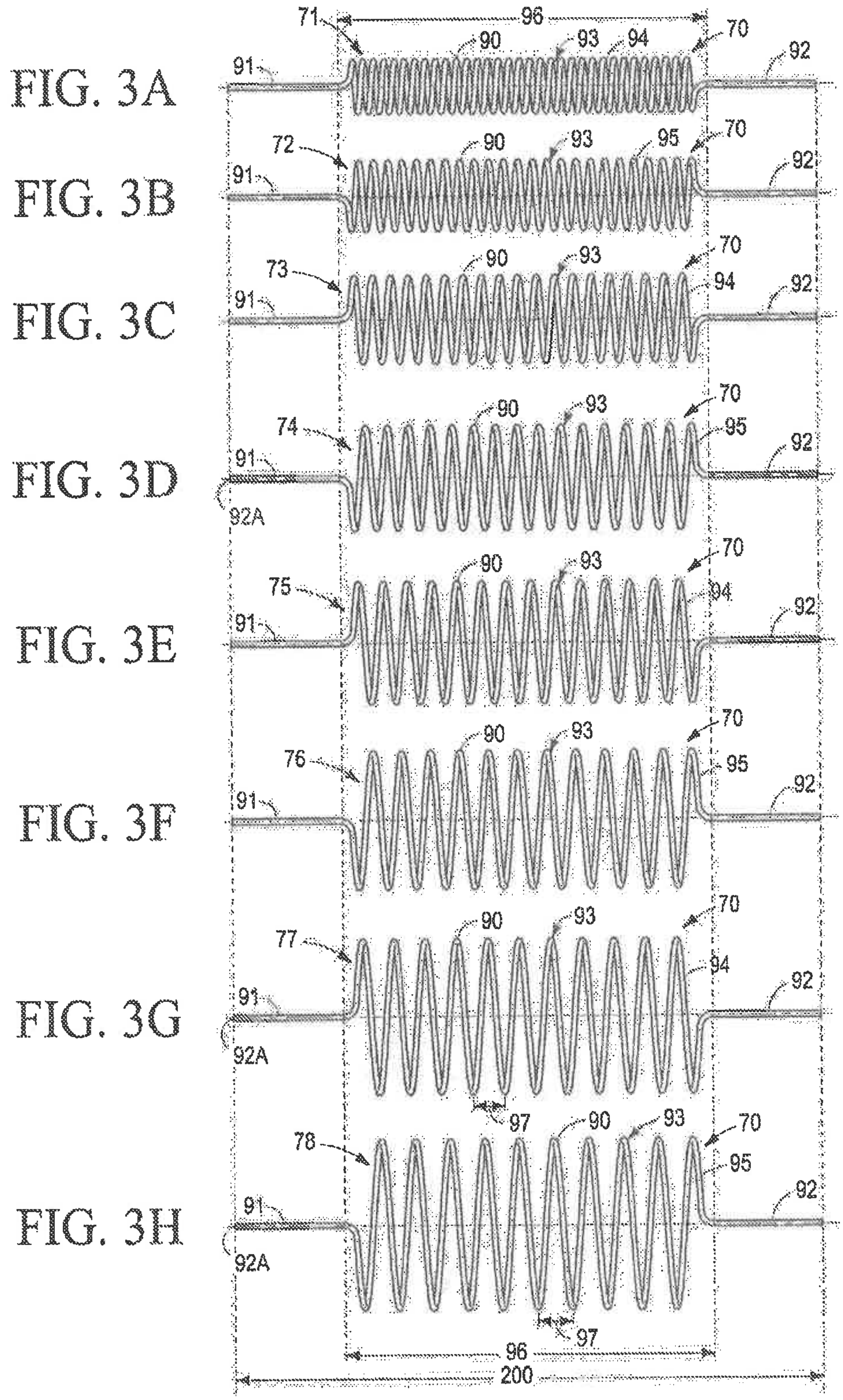
FIG. 3A
FIG. 3B
FIG. 3C
FIG. 3D
FIG. 3E
FIG. 3F
FIG. 3G
FIG. 3H
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92A
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97
200

FIG. 3A1

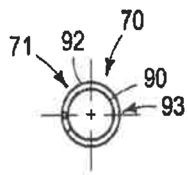


FIG. 3B1

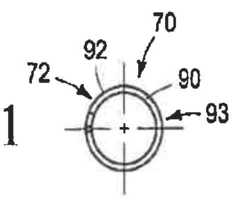
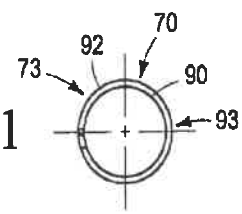


FIG. 3C1



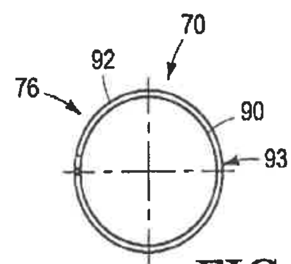
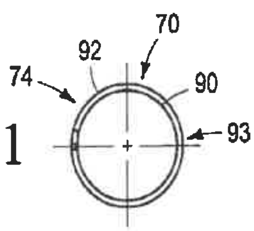


FIG. 3F1

FIG. 3D1



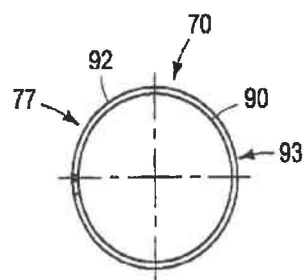
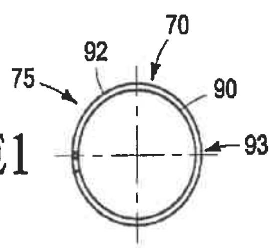


FIG. 3G1

FIG. 3E1



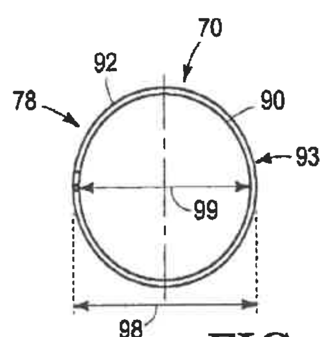


FIG. 3H1

HEAT EXCHANGER

TECHNICAL FIELD

The present invention relates to a heat exchanger which finds usefulness in cascade refrigeration systems.

BACKGROUND OF THE INVENTION

A cascade heat exchanger as used in a refrigeration system has traditionally been either "shell and tube" or "plate" type in construction. Typical "shell and tube" heat exchangers have a multiplicity of straight tubes which are expanded into opposing tube sheets that are contained within a cylindrical shell. Because of this style of construction, the tubes are held rigidly between the tube sheets and consequently, high axial strain, stresses, and other forces, can occur during relatively large changes in temperature and pressure of the refrigerant which is being utilized. Under these circumstances if the strain and accompanying stresses reaches a high enough value the individual tubes may crack and rupture resulting in cross-contamination of the two refrigerants which are being employed. This may result in damage to the overall refrigeration system.

Shell and tube heat exchangers occupy a relatively large spatial volume for a given heat transfer duty, and is therefore not considered a "compact" heat exchanger. Plate heat exchangers, on the other hand, can be made in a "plate and shell" or a "plate and frame"; or in a "welded plate" configuration. All of the aforementioned forms of the prior art include a stack or multiple of formed plates, having a manifold system which distributes the two refrigerants, being employed, alternatively, between the plates such that one of the refrigerants flows on one side of each of the plates, while the other refrigerant flows on the opposite side of the respective plate. These plate heat exchangers are considered to be "compact," but because the plates are held rigidly in a given spatial relationship, one relative to the other, high strains and stresses can form in the plate material when the heat exchanger is exposed to large changes in temperature and pressure of the respective refrigerants.

Ultimately, acceptable performance of any form of a prior art cascade heat exchanger depends largely upon uniform flow distribution of both refrigerants within multiple tubes or plates. This uniform flow distribution is typically difficult to achieve with conventional "shell and tube" and "plate" type heat exchangers under two phase flow conditions (that is condensing or evaporating) of the refrigerants.

While the aforementioned prior art cascade heat exchangers have operated with varying degrees of success, problems still remain in their use when deployed in various environments. Chief among the problems exhibited by these prior art devices include the frequent failure of these prior art designs due to the excessively high strain and stress experienced by the tubes and plates as mentioned, above. Still further, these prior art cascade heat exchangers have a very high cost of construction. Moreover, and as mentioned briefly above, these prior art cascade heat exchangers often present a situation where the non-uniform distribution of a two-phase refrigerant flow to multiple circuits or passages within the prior art devices results in relatively poor heat transfer performance. Still further these prior art cascade heat exchangers often have large internal volume and space requirements which is the case for the shell and tube type construction as mentioned, above. Finally, the prior art devices appear to uniformly prevent the reversing of the two refrigerants for purposes of defrosting the prior art device.

Therefore, a heat exchanger which avoids the problems associated with the prior art devices utilized, heretofore, is the subject matter of the present invention.

SUMMARY OF THE INVENTION

A first aspect of the present invention relates to a heat exchanger which includes an exterior container which defines an internal cavity; a refrigerant distribution tube which is positioned within the internal cavity, and which is further coupled in fluid receiving relation relative to a first source of refrigerant; and a multiplicity of closely nested, refrigerant tubes which are located within the internal cavity of the exterior container, and which are further disposed in closely spaced, radially outwardly oriented positions relative to the refrigerant distribution tube, and wherein the respective refrigerant tubes each have a predetermined length dimension, and individually form a helical coil which has a given length dimension, and pitch, and wherein each of the refrigerant tubes, and the respective helical coils that the individual refrigerant tube forms have the same length dimension, and wherein the respective refrigerant tubes are each coupled in fluid receiving relation relative to a second source of a refrigerant.

Still another aspect of the present invention relates to a heat exchanger which includes an exterior container which has opposite, first and second ends, and which further defines an internal cavity, and wherein the exterior container is further defined by a longitudinal axis which extends between the first and second ends thereof; a refrigerant distribution tube which is positioned within the internal cavity of the exterior shell, and which is further oriented along the longitudinal axis thereof, and wherein the refrigerant distribution tube has a first refrigerant intake end which is located within the internal cavity, and in spaced relation relative to the first end of the exterior container, and a second refrigerant exhaust end, and wherein the second refrigerant exhaust end is located within the internal cavity of the exterior shell, and in spaced relation relative to the second end of the exterior container, and wherein the first end of the refrigerant distribution tube is fluid flowingly coupled to a source of a first refrigerant; and a multiplicity of refrigerant tubes which are received within the internal cavity of the exterior container, and which each have an equal length dimension, and wherein each refrigerant tube further defines a helically shaped coil having a coil length, and wherein each helical coil is substantially of equal length, and wherein the respective refrigerant tubes are further individually located in a radially outwardly spaced relationship relative to the longitudinal axis thereof, and wherein the respective helical coils defined by each of the refrigerant tubes are either left-handed, or right-handed in orientation, and are further nested together, in both a longitudinal and a radially outward direction, so as to orient the respective refrigerant tubes in a predetermined, closely spaced relationship which occupies a preponderance of the internal cavity of the exterior container, and wherein the respective refrigerant tubes each have a first intake end, and a second exhaust end, and wherein the first end of the respective refrigerant tubes are further fluid flowing coupled to a second source of a refrigerant, and the second end of the refrigerant tubes is disposed in fluid flowing communication with the second end of the external container.

These and other aspects of the present invention we discuss in greater detail hereinafter.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Preferred embodiments of the invention are described below with reference to the following accompanying drawing.

FIG. **1** is a perspective, side elevation view of the heat exchanger of the present invention.

FIG. **2** is a longitudinal, vertical, sectional view of the present invention and which is taken from a position along line **2-2** of FIG. **1**.

FIG. **3A** is a side elevation view of a first form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is left handed.

FIG. **3A1** is an end view of the refrigerant tube which is seen in FIG. **3A**.

FIG. **3B** is a side elevation view of a second form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is right handed.

FIG. **3B1** is an end view of the refrigerant tube as seen in FIG. **3B**.

FIG. **3C** is a side elevation view of a third form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is left handed.

FIG. **3C1** is an end view of the refrigerant tube as seen in FIG. **3C**.

FIG. **3D** is a side elevation view of a fourth form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is right handed.

FIG. **3D1** is an end view of the refrigerant tube as seen in FIG. **3D**.

FIG. **3E** is a side elevation view of a fifth form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is left handed.

FIG. **3E1** is an end view of the refrigerant tube as seen in FIG. **3E**.

FIG. **3F** is a side elevation view of a sixth form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is right handed.

FIG. **3F1** is an end view of the refrigerant tube as seen in FIG. **3F**.

FIG. **3G** is a side elevation view of a seventh form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is left handed.

FIG. **3G1** is an end view of the refrigerant tube as seen in FIG. **3G**.

FIG. **3H** is a side elevation view of an eighth form of a refrigerant tube finding usefulness in the present invention, and which defines a helical coil which is right handed.

FIG. **3H1** is an end view of the refrigerant tube as seen in FIG. **3H**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

The present invention is generally indicated by the numeral **10** in FIGS. **1** and **2**, respectively. The heat exchanger **10** is defined, at least in part, by an exterior container **11** which is herein illustrated as being cylindrically shaped, and which has a first end **12**, and an opposite, second end **13**. The exterior container **11** is defined by an exterior facing sidewall surface **14**, and an opposite, interior facing sidewall surface **15**. Still further the exterior container **11** has a longitudinal axis **16** which extends between the first and second ends **12** and **13**. The exterior container **11** includes an internal cavity **20** which is defined, at least in part, by the interior facing sidewall surface **15**. The internal cavity has a given transverse cross-sectional dimension, and area, which defines, at least in part, a flow area which will be discussed in greater detail, hereinafter. The first end **12** of the exterior container defines a first aperture **21** which extends therethrough, and which further communicates with the internal cavity **20**. Similarly, the second end **13** of the exterior container **11** defines a second aperture **22** which also communicates with the internal cavity **20**. First, second and third sidewall apertures **23**, **24** and **25** are formed in the exterior container **11** and allow communication to the internal cavity **20** of the exterior container **11**.

Referring now to FIGS. **1** and **2**, the present invention **10** includes a pair of refrigerant couplers which are generally indicated by the numeral **30**, and which are further located at the opposite, first and second ends **12** and **13** of the exterior container **11**. The respective refrigerant couplers **30** include a first refrigerant delivery coupler which is generally indicated by the numeral **31**; and a second, refrigerant removal coupler **32**. The respective refrigerant couplers **30** are coupled or mounted in occluding, fluid flowing relation relative to the respective first and second apertures **12** and **13**, and which are formed in or defined by the first and second ends **12** and **13**, of the exterior container **11**. The first refrigerant delivery coupler **31** has a somewhat bell shaped main body **33**. The main body **33** defines an internal cavity **34** which has a variable cross sectional dimension. The main body **33** has a first intake end **35**, and a second, exhaust end **36** which is coupled in fluid delivering relation relative to the first end **12** of the exterior container **11**. The second refrigerant removal coupler **32** appears in some respects to have similar construction, but operates somewhat differently from the first refrigerant delivery coupler **31**. In this regard, the second refrigerant removal coupler **32** has a main body **43** having a similar shape when compared to first refrigerant delivery coupler **31**. Still further, the main body **43** has or defines an internal cavity **44** having a variable cross-sectional dimension. The main body **43** has a first, intake end **45** which is sealably coupled in fluid receiving relation relative to the second end **13** of the exterior container **11**, and which further occludes the second aperture **22**. The main body **43** additionally has a second, exhaust end **46** opposite to the first intake end **45**.

Referring again to FIG. **2**, the present invention **10** includes first and second refrigerant distribution plates **51** and **52** and which are individually placed in a substantially occluding relationship relative to the first and second apertures **21** and **22**, respectively. The first and second refrigerant distribution plates are substantially circular in shape, and have a main body **53** which is defined by a first and second surface **54** and **55**. The first and second surfaces are substantially planar, and are further disposed in spaced relation one relative to the other. The main body **53** of the respective first and second refrigerant distribution plates **51** and **52** is also defined, at least in part, by a peripheral edge **56**. The main body **53** has formed therein a multiplicity of spaced apertures **57** which are utilized to receive, and fluid sealably couple to individual refrigerant tubes which will be discussed in greater detail, hereinafter. The respective spaced apertures **57** are formed in a predetermined pattern for the purposes which will be set forth in greater detail, below. The main body **53** is also sealably coupled or otherwise affixed to one end of the respective refrigerant couplers **30** as seen in the drawings.

The present invention **10** includes an elongated refrigerant distribution tube **60**, which is positioned within the internal cavity **20** as defined by the exterior container **11**. The refrigerant distribution tube is positioned substantially along, and is coaxially aligned relative to the longitudinal axis **16** of the exterior container **11** as seen in FIG. **2**. The refrigerant distribution tube has a main body **61** which has a predetermined length dimension, and which is less than the length dimension of the exterior container **11**. The main body **61** has a first end **62**, which is positioned in inwardly spaced relation relative to the first end **12** of the exterior container, and is further located within the internal cavity **20** thereof; and an opposite second end **63**, and which is located in predetermined spaced relation relative to the second end **13** of the exterior container **11**. The first end **62** of the main body is coupled to a conduit **64** which extends generally radially outwardly therefrom, and further is received, and passes through the aperture **23**, and which is formed in the exterior container **11**. The conduit **64** is coupled in fluid receiving relation relative to a first source of a low pressure refrigerant, and which is generally indicated by the numeral **65**, and which is further delivered to the conduit **64**. The conduit **64** consequently delivers the low pressure refrigerant **65** to the first end **62** of the main body **61**. The first source of the low pressure refrigerant **65** then travels along the main body **61**, from the first end **62**, to the second end **63**, and where the low pressure refrigerant **65** is then released into the internal cavity **20** as defined by the exterior container **11**. The low pressure refrigerant has a pressure range of about 5 PSI [A] to about 315 PSI[A]. An exemplary first source of a low pressure refrigerant **65** comprises ammonia which, when used in a cooling operation, evaporates upon exiting the second end **63** for the purposes which will be described, hereinafter. Other useful low pressure refrigerants include, but are not limited to, halocarbons refrigerants, and hydrocarbon refrigerants, respectively.

As seen in FIG. **2** and following, a multiplicity of closely nested, refrigerant tubes **70** are located within the internal cavity **20** of the exterior container **11**. These refrigerant tubes are disposed in closely spaced, radially outwardly oriented positions relative to the refrigerant distribution tube **60**, and further occupy a majority of cross sectional area or space defined by the internal cavity **20**. The multiplicity of closely nested refrigerant tubes **70** include first, second, third, fourth, fifth, sixth, seventh and eighth forms, and which are generally indicated by the numerals **71** through **78** respectively, and which further are seen in FIGS. **3A** through 3H; and FIGS. **3A1** through FIG. **3H1**, respectively. The respective refrigerant tubes **70** each are defined by a main body **90** which has a first end **91**, and a second end **92** with a length dimension **200** therebetween. Each main body **90** has an identical outside diametral dimension, and further defines a fluid passageway **92A** which extends between the first and second end **91** and **92**. The fluid passageway **92A** has a similar or identical inside diametral dimension. The main body **90** of each form is fabricated of a metal tube which has the same length dimension **200** when measured between the first and second ends **91** and **92**. This feature that each refrigerant tube **20** be identical in length **200** to each of the other refrigerant tubes **20**, is an important operational aspect of the present invention **10**. This feature will be discussed at greater length, below. Further, the main body **90** is formed, at least in part, into a helical coil **93**. The helical coil of the respective forms, **71-78**, while having a similar overall length dimension **96**, have different characteristics, as set forth below. In this regard, the helical coil **93** may take on the form of a left-handed coil which is generally indicated by the numeral **94**, or a right-handed coil which is generally indicated by the numeral **95**. With regard to the definition of a left-handed or right-handed helical coil it should be understood that if a helix is held, and one was to look along a line of sight which is directed along the helix axis, if a clockwise screwing motion moves the helix away from the observer, the helix form is considered a right-hand helix. On the other hand, if the same clockwise rotation of a helix moves the helix towards the observer then this helix form is considered a left-hand helix. Left or right handedness, or chirality, is a property of the helix, and not that, of the perspective. For example, a right-handed helix cannot be turned to look like a left-handed one unless it is viewed in a mirror and vice versa. Further each helix has a pitch **97**. The eight forms **71-78** each have individually discrete pitches **97**. A pitch for purpose of this application is defined as the height of one complete helix turn when it is measured parallel to the axis of the helix. In the present invention **10**, the helical coil length which is indicated by the line **96** for each of the forms of the refrigerant tubes **71** through **78** respectively, remains identical, while the pitch **97** as well as the outside diameter and inside diametral dimension **98** and **99** of the helical coil **93**, respectively, vary for the several forms **71-78** of the refrigerant tubes **70**. The variation of the left handed and right handed nature **94** and **95** of the helical coil **93**, as well as a variation of the pitch **97**, and outside diameter **98** of the respective helical coils **93** allows a multiplicity of refrigerant tubes **70**, (**23** as seen in the form of the invention as seen in FIG. **2**), to be closely nested in a closely packed, yet slightly spaced orientation within the internal cavity **20** of the exterior container **11** so as to achieve the refrigeration benefits that are discussed in greater detail, below. At least one pair of helical coils **93** are arranged in a double helix configuration wherein the helical coils are coaxially screwed together, and the axis of each of the helical coils **93** arranged in the double helix configuration that are coaxially screwed together is coaxially aligned with the refrigerant distribution tube **20**.

Referring now to FIG. **3A** the first form **71**, of the refrigerant tube **70**, and which has the characteristics as noted, above, is illustrated. In the construction as seen in FIG. **2**, only one refrigerant tube **70** having this construction, or shape, is employed, and is further positioned within the internal cavity **20**. The pitch **97** of the first form **71** of the refrigerant tube **70** is equal to about 1.2 to about 2.0 times the outside diametral dimension of the refrigerant tube **70**. The first form **71** further is left-handed **94** in orientation, and additionally has an inside diametral dimension **99** which is sized so as to telescopingly receive, and be radially spaced outwardly from, the refrigerant distribution tube **60**. The outside diametral dimension **98** of the first form **71** allows it to be telescopingly and coaxially received within the second form **72**, of the refrigerant tube **70**, as see in FIG. 3B. As should be understood, the second form **72** of the refrigerant tube **70** is right handed **95**, and in the construction as seen in FIG. **2**, two of the refrigerant tubes having the form **72** are coaxially screwed together and are then installed in the internal cavity **20** at a location which is radially, outwardly, relative to the first form **71** of the refrigerant tube **70**. The pitch **97** of the second form **72** of the refrigerant tube **70** is equal to about 2.4 to 4.0 times the outside diametral dimension of the refrigerant tube **70**. The second form **72** of the refrigerant tube **70** has an outside coil diameter **98** which permits it to be telescopingly received within the inside diametral dimension **99** of the third form **73**, of the refrigerant tube **70** (FIG. 3C). In the construction as seen in FIG. **2**, two refrigerant tubes having the shape of the third form

73, and which are both of left-handed **94**, are coaxially screwed together. The pitch **97** of the third form **73** is equal to about 2.4 to about 4.0 times the outside diametral dimension of the refrigerant tube **70**. Referring now to FIG. **3**D, the fourth form **74**, of the refrigerant tube **70** is shown. The fourth form **74** has an inside diametral dimension **99** which allows the third form **73** to be telescopingly and coaxially received therein. In the present design, three of the refrigerant tubes **70** having the shape of the fourth form **74**, and which are each right-handed **95**, are coaxially screwed together. The pitch **97** of the fourth form **74** of the refrigerant tubes **70** is equal to about 3.6 to about 6 times the outside diametral dimension of the refrigerant tube **70**. A fifth form **75** of the refrigerant tubes **70** is seen in FIG. 3E. The fifth form **75**, which is left-handed **94**, has an inside diametral dimension **99** which is sized so as to telescopingly receive the fourth form **74**, therein. In the present construction as seen in FIG. **2**, 3 left handed **94** refrigerant tubes **75** are coaxially screwed together, and are then installed in internal cavity **20**. The pitch **97** of the fifth form **75** of the refrigerant tubes **70** is equal to about 3.6 to about 6 times the outside diametral dimension of the refrigerant tubes **70**.

Referring still to FIGS. **3**A-**3**H, the sixth form **76** of the refrigerant tubes **70** is seen in FIG. 3F. The sixth form **76** has an inside diametral dimension **99** which is sized so to telescopingly receive the fifth form **75** therein. In the present form of the invention, 3 right-handed **95** refrigerant tubes **70** of the fifth form **75** are coaxially screwed together, and are then installed in the internal cavity **20**. The pitch **97** of the sixth form **76** is equal to about 3.6 to about 6 times the outside diametral dimension of the refrigerant tube **70**. The seventh form **77**, of the refrigerant tubes **70**, is seen in FIG. 3G. The seventh form **77** has an inside diametral dimension **99** which is sized so as to telescopingly receive the sixth form **76** therein. In the present form of the invention, 4 left-handed **94** refrigerant tubes **70** of the seventh form **77** are coaxially screwed together, and are then installed in the internal cavity **20**. The pitch **97** of the seventh form **77** is equal to about 4.8 to about 8 times the outside diametral dimension of the refrigerant tube **70**. The eighth form **78** of the refrigerant tubes **70** is seen in FIG. 3H. The eighth form **78** has an inside diametral dimension **99** which is sized so as to telescopingly receive the seventh form **77** therein. In the present form of the invention 4 right-handed **95** refrigerant tubes **70** of the eighth form **78** are coaxially screwed together, and then installed in the internal cavity **20**. The pitch **97** of the eighth form **78** is equal to about 4.8 to about 8 times the outside diametral dimension of the refrigerant tube **70**.

As will be understood from the discussion, above, 23 refrigerant tubes **70**, having eight different forms **71**-**78**, and which are either left handed **94** or right handed **95** in orientation, and which further have different pitches **97**, are utilized to form the closely nested refrigerant tube structure which is located within the internal cavity **20**, and which further achieves the benefits of the invention **10**, as described herein.

The respective refrigerant tubes **70**, which are nested in the internal cavity **20**, and in particular the first end **91**, thereof, is individually coupled in fluid flowing relation relative to the first refrigerant distribution plate **51**. As such, the main body **90** of each of the refrigerant tubes **70** are coupled in fluid receiving relation relative to a second source of refrigerant which is generally indicated by the numeral **110**. The second source of the refrigerant **110** is a high pressure refrigerant having a pressure of about 90 PSI [A] to 750 PSI [A]. In one form of the invention **10**, the second source of the refrigerant **110** condenses when the heat exchanger **10** is used in a cooling operation. Further, and in one form of the invention **10**, this high pressure, second source of the refrigerant **110** is carbon dioxide. In addition to the foregoing, the second end **92** of each of the respective refrigerant tubes **70** are individually received in each of the multiplicity of spaced apertures **57**, and which are formed in the second refrigerant collection plate **52**. Therefore, it should be understood that the second source of refrigerant **110** moves along the fluid passageway **92**A from the first end **91**, to the second end **92**, for the purposes which will be described, hereinafter. As stated above, the respective refrigerant tubes **70** each have a predetermined length dimension as measured between the first and second ends **91**, and **92**, and further individually form a helical coil **93** which has a given length dimension **96**, and discrete pitch **97**. In the arrangement as seen in the drawings (FIG. **3**A-FIG. **3**H, respectively), each of the refrigerant tubes **70**, and the respective helical coils **93** that are formed by the individual refrigerant tubes **70** have the same overall length dimension. Stated somewhat differently, the overall length dimension of each of the refrigerant tubes as measured between the first end **91**, and second end **92**, and which is taken along the main body **90**, thereof, is substantially identical. Further, the exterior length dimension **96** of the coil **93**, is substantially identical. However, the pitch **97**, and the inside and outside diametral dimensions **99**, and **98**, respectively, of the individual helical coils **93**, which are defined by the several forms **71**-**78** vary, so that the respective forms of the refrigerant tubes **71** through **78**, can be received and oriented in the closely nested, spaced relationship within the internal cavity **20** as seen in FIG. **2**. This closely nested relationship facilitates a substantially uniform flow, and distribution of the first source of the refrigerant **65**, once the first source of the refrigerant **65** leaves the refrigerant distribution tube **60**, enters the internal cavity **20** of the exterior shell or container **11**, and then vaporizes during a cooling operation. Once the refrigerant tubes **70** are appropriately nested within the internal cavity **20** it should be understood that the exterior container **11** will have a transverse cross-sectional flow area **111** which is defined between the refrigerant distribution tube **60**, and the interior facing surface **15** of the exterior container. In the closely packed, and substantial uniformly spaced orientation, the helical coils **93** collectively occupy a preponderance of the space defined by the internal cavity **20**, and further facilitates a flow velocity of the vaporized first refrigerant **65** within the transverse cross-sectional flow area **111** of less than about 50 feet per second. In the arrangement as seen in the drawings, the respective refrigerant tubes **70** impart a substantially similar pressure drop, and an equal flow of the condensing second source of the refrigerant **110** as the condensing refrigerant travels between the first and second ends **91** and **92** thereof, and when the heat exchanger **10** is being utilized in a cooling operation. In the present form of the invention, the respective refrigerant tubes **70**, when exposed to different refrigerant pressures and temperatures, resiliently expand and contract in length. Upon expansion or contraction of the respective refrigerant tubes **70**, the helical coil **93** construction of the respective refrigerant tubes **70** produces low physical strain and stress on the opposite ends **91** and **92**, respectively, so as to impede an expansion or contraction induced fluid flowing separation of the opposite ends **91** and **92** of the respective refrigerant tubes **70** from either the refrigerant distribution plate **51**, or refrigerant collection plate **52**, respectively. This substantially prevents an accidental mixing of the first and second sources of refrigerant **65** and **110**, respectively.

The present invention 10 is operable to utilize a second source of a high pressure refrigerant, and which is generally indicated by the numeral **110**. The second source of the refrigerant which may include, for example, carbon dioxide, and which has a pressure of about 90 PSI[A] to about 750 PSI [A] is supplied to the first refrigerant delivery coupler **31** as earlier disclosed. The second source of high pressure refrigerant **110** as it enters the first refrigerant delivery coupler **31** at the first intake end **35** experiences a reduction in pressure as it moves between the first intake end **35**, and the second exhaust end **36**. The second source of refrigerant **110** then enters the first end **91** of each of the respective refrigerant tubes **70**, and then travels to the second end **92** where it then enters the second refrigerant removal coupler **32**. The second source of the refrigerant **110** is then utilized, again, for another refrigeration cycle.

As earlier discussed, the internal cavity **20** has a given cross-sectional flow area **111** which is defined between the refrigerant distribution tube **60**, and the interior facing surface **15** of the exterior container **11**. Further, the multiplicity of closely nested refrigerant tubes **70** are substantially equally spaced, one from the other, so as to provide a resulting cross-sectional flow area **111** which facilitates a flow velocity of the vaporized first refrigerant **65** within the transverse cross-sectional flow area **111** of less than 50 feet per second. The first refrigerant **65**, upon exiting the second end **63** of the refrigerant distribution tube **60** forms a low pressure vapor which then moves vertically, upwardly and comes into heat conducting contact with each of the refrigerant tubes **70**. The low pressure vapor **65** then escapes from the internal cavity **20** by way of a first fluid passageway which is generally indicated by the numeral **112**, and which extends through the aperture **25** which is formed in the exterior container **11**. The low pressure vapor **65** then is recycled or employed again in another refrigeration cycle. The present invention **10** further includes a second fluid passageway **113** which is located near the second end **13** of the exterior container **11** as seen in FIG. **2** and which passes through the aperture **24** which is formed in the exterior container **11**. The second fluid passageway **113** operates, or is useful when the heat exchanger **10** is being employed in a defrosting or heating mode. In this regard, it should be understood that the first fluid passageway **112**, which his located near the first end **12** of the exterior container **11**, communicates in fluid flowing relation relative to the internal cavity **20** thereof; and the second fluid passageway **112** which is located near the opposite second end **13**, also communicates with the internal cavity **20**. The first fluid passageway **112**, permits vapor formed of the first refrigerant **65** to escape from the internal cavity **20** of the exterior container **11** when the heat exchanger **10** is being utilized in a cooling operation. However, the first fluid passageway **112** further permits vapor derived from the first refrigerant **65** to enter the internal cavity **20** of the exterior container **11**, and the second fluid passageway **113** permits a condensed liquid derived, at least in part, from the first refrigerant **65**, to leave, or be removed from the internal cavity **20** when the heat exchanger **10** is being utilized in a heating or defrosting operation. As seen in FIG. **2** the first fluid passageway **112** is located elevationally above the second fluid passageway **113**.

Operation

The operation of the described embodiments of the present invention are believed to be readily apparent, and are briefly summarized at this point.

In its broadest aspect the present invention relates to a heat exchanger **10** which finds particular usefulness in a cascade refrigeration system, and more specifically to a heat exchanger **10** which includes an exterior container **11**, and which further defines an internal cavity **20**. A refrigerant distribution tube **60** is positioned within the internal cavity **20**, and is further coupled in fluid receiving relation relative to a first source of a refrigerant **65**. In its broadest aspect, the heat exchanger **10** further includes a multiplicity of closely nested, and spaced refrigerant tubes **70** which are located within the internal cavity **20** of the exterior container **11**, and which are further disposed in closely spaced, radially outwardly oriented positions relative to the refrigerant distribution tube **60**. The respective refrigerant tubes **70** each have a predetermined, and similar length dimension (as measured from end to end); and individually form a helical coil **93** which has a given and similar length dimension **96**, and a variable, or individually discrete pitch **97**. The respective refrigerant tubes **70** are each coupled in fluid receiving relation relative to a second source of a refrigerant **110**. In one possible form of the invention **10** as see in FIG. **2**, 23 refrigerant tubes **70**, and which comprise 8 different refrigerant tube forms **71-78**, are nested together to form the structure as illustrated.

In its broadest aspect, the present invention **10** includes, as noted above, a first source of a refrigerant **65** which is a low pressure refrigerant; and a second source of refrigerant **110** which is considered a high pressure refrigerant. In this regard, the first source of the refrigerant **65** is a low pressure refrigerant which evaporates or vaporizes when the heat exchanger **10** is used in a cooling operation; and the second source of the refrigerant **110** is a high pressure refrigerant which condenses when the heat exchanger **10** is used in a cooling operation. On the other hand, the first source of the refrigerant **65** may condense when the heat exchanger **10** is used in the heating or defrosting operation, and the second source of the refrigerant **110** may evaporate when the heat exchanger is used in the same heating or defrosting operation.

The present invention **10** includes, as noted above, an exterior container **11** which has opposite ends **12** and **13**, and wherein a refrigerant distribution plate **51** is sealably mounted on one end **12** of the exterior container. Each of the refrigerant tubes **70**, as noted above, have a first end **91** which are individually coupled in fluid receiving relation relative to the refrigerant distribution plate **51**. The refrigerant distribution plate is coupled in fluid receiving relation relative to the second source of the refrigerant **110**. A refrigerant collection plate **52** is sealably mounted on the opposite end **13** of the exterior container **11**. Each of the refrigerant tubes **70** have a second end **92**, and which are individually coupled in a fluid discharging relation relative to the refrigerant collection plate **52**. It should be understood that the refrigerant distribution plate **51**, and refrigerant collection plate **52** each have a multiplicity of symmetrically spaced apertures **57** which are formed therein. The symmetrically spaced apertures are individually sized so as to matingly and fluid flowingly couple with one of the first or second ends **91** or **92** of the respective refrigerant tubes **70**. The refrigerant collection and distribution plates **51** and **52**, acting in combination, orient at least in part the respective refrigerant tubes **70** in nested, equally spaced positions one relative to the other, and within the internal cavity **20** of the exterior container **11**, so as to facilitate a substantially uniform flow and distribution of the vaporized, first source of refrigerant **65**, once the first source of the refrigerant **65** leaves the refrigerant distribution tube 60, enters the internal cavity 20 of the exterior container 11, and then vaporizes during a cooling operation.

It should be understood by a study of FIG. 2 that a transverse cross-sectional flow area 111 is defined within the internal cavity 20 of the exterior container 11 when the multiplicity of nested, closely spaced refrigerant tubes 70 are received within the internal cavity 20. The respective refrigerant tubes 70 have an overall length dimension, when measured between the opposite ends 91 and 92, and along the main body 90, which are substantially equal. The transverse cross-sectional flow area 111 facilitates or permits a flow velocity of the vaporized, first refrigerant 65 within the transverse cross-sectional flow area 111 of less than about 50 feet per second. In the arrangement as seen in the drawings, the exterior container 11 further has a longitudinal axis 16, and the respective refrigerant tubes 70 which form each of the helical coils 93 are each coaxially oriented relative to the longitudinal axis 16 of the exterior container 11. The exterior container 11 has a length dimension as measured between the first and second ends 12 and 13, and further the respective helical coils 93 which are defined, at least in part, by the main body 90, of each of the refrigerant tubes 70, has a length dimension 96, which is less than the length dimension of the exterior container 11. Each helical coil 93 has the same length dimension 96. The exterior container 11 further includes or defines a first fluid passageway 112 which is located near one end 12 of the exterior container, and which communicates in fluid flowing relation relative to the internal cavity 20 thereof. The exterior container 11 further defines a second fluid passageway 113 which is located near the opposite end 13 of the exterior container 11, and further communicates in fluid flowing relation relative to the internal cavity 20. The first fluid passageway 112 permits vapor formed of the first refrigerant 65 to escape from the internal cavity 20 of the exterior container 11 when the heat exchanger 10 is being utilized in a cooling operation. On the other hand, the first fluid passageway 112 permits vapor formed of the first refrigerant 65 to enter the internal cavity 20 of the exterior container, and the second fluid passageway 130 permits a liquid which is derived, at least in part, from the first refrigerant 65, to leave the internal cavity 20, which is further defined by the exterior container 11, when the heat exchanger 10 is being utilized in a heating or defrosting operation. The first fluid passageway 112 is located elevationally above the second fluid passageway 113.

In the arrangement as seen in the drawings it should be understood that the respective refrigerant tubes 70 impart a substantially similar pressure drop, and an equal flow of the condensing refrigerant 110 as the condensing, second source of refrigerant 110 travels between the first and second ends 91 and 92 of the respective refrigerant tubes 70 when the heat exchanger 10 is being utilized in a cooling operation. In one possible form of the invention the first refrigerant 65 comprises ammonia, and the second source of refrigerant comprises carbon dioxide. The respective refrigerant tubes 70, when exposed to changes in refrigerant pressure, and temperature are individually operable to resiliently expand and contract in length in view of the presence of the helical coil 93. Upon expansion or contraction of the respective refrigerant tubes 70, the helical coil construction 93 of each of the respective refrigerant tubes 70 produces or facilitates, at least in part, a relatively low physical strain and stress on the opposite ends 91 and 92, thereof, so as to impede the development of an expansion or contraction induced fluid-flowing separation of the opposite ends 91 and 92 of the refrigerant tubes 70 from either the refrigerant distribution plate 51 and/or the refrigerant collection plate 52, respectively. This operational aspect of the invention prevents an accidental or inadvertent mixing of the first and second sources of the refrigerant 65 and 110, respectively. The respective refrigerant tubes 70, as described herein, each form a helical coil 93 having a given bend radii. The bend radii of the respective helical coils 93, which are formed by the individual refrigerant tubes 70, increases when the bend radii of each of the refrigerant tube 71-78 is measured along a line which extends radially, outwardly, from the refrigerant distribution tube 60, and towards the exterior container 11. Each helical coil 93 which is defined by the individual refrigerant tubes 70 defines a predetermined outside coil diameter 98. The respective helical coils 93 which are defined by the respective refrigerant tube 70 are either left handed 94, or right handed 95 in orientation. The respective refrigerant tubes 70 each have an outside diametral dimension 98, and the respective helical coils 93 are substantially equally, and symmetrically spaced from an adjacent helical coil 93 which is defined by a refrigerant tube 70, when the respective helical coils 93 are nested together, and located within the internal cavity 20 of the container 11 as seen in FIG. 2. Each form 71-78 of the refrigerant tubes 70 define, at least in part, a helical coil 93 which has a predetermined pitch 97. When appropriately nested together, and located within the internal cavity 20, the respective refrigerant tubes 70 are spaced from adjacent refrigerant tubes 70 by a distance of about 1.2 to about 2.0 times the outside diametral dimension of the respective refrigerant tubes 70.

Therefore it will be seen that the present heat exchanger 10 provides many advantages over the prior art heat exchangers which have been utilized, heretofore, in cascade-type refrigeration systems. The present heat exchanger 10 is robust, compact, and can be scaled to various sizes, and is further designed so as to prohibit expansion and contraction related damage that might be occasioned by changes in refrigerant temperatures and pressures. The present invention's compact design further facilitates many advantages in the design and operation of cascade refrigeration systems which have not been possible, heretofore.

In compliance with the statute the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications when the proper scope of the appended claims appropriately interpreted according with the Doctrine of Equivalence.

We claim:

1. A heat exchanger, comprising:

an exterior container which has opposite first and second ends, and defines an internal cavity, and wherein the exterior container is further defined by a longitudinal axis that extends between the opposite first and second ends;

a refrigerant distribution tube which is positioned within the internal cavity of the exterior container, and is oriented along the longitudinal axis thereof, and wherein the refrigerant distribution tube has a first refrigerant intake end which is located within the internal cavity, and in spaced relation relative to the first end of the exterior container, and a second refrigerant exhaust end, and wherein the second refrigerant exhaust end is located within the internal cavity, and in spaced relation relative to the second end of the exterior container, and wherein the first end of the refrigerant distribution tube is fluid flowingly coupled to a source of a first refrigerant; and

a multiplicity of refrigerant tubes within the internal cavity of the exterior container and each of the multiplicity of refrigerant tubes has a length dimension, and wherein each of the multiplicity of refrigerant tubes are equal in length, and wherein each of the multiplicity of refrigerant tubes further defines a helically shaped coil having a coil length, and wherein each helical coil is equal in length, and wherein the multiplicity of refrigerant tubes are further individually located in a radially outwardly spaced relationship relative to the longitudinal axis of the exterior container, and wherein the respective helical coils defined by each of the multiplicity of refrigerant tubes are either left hand, or right handed in orientation, and are further helically nested together, in both a longitudinal and a radially outward direction, so as to orient the respective multiplicity of refrigerant tubes in a predetermined, closely spaced helical relationship which occupies a majority of a volume of the internal cavity of the exterior container, and wherein the respective multiplicity of refrigerant tubes each have a first intake end, and a second exhaust end, and wherein the first end of each of the multiplicity of refrigerant tubes are further fluid flowing coupled to a second source of a refrigerant, and the second end of each of the multiplicity of the refrigerant tubes is disposed in fluid flowing communication with the second end of the external container.

2. A heat exchanger as claimed in claim 1, and further comprising:

a refrigerant distribution plate which is sealably mounted on the first end of the exterior container, and wherein the first end of each of the helical coil shaped refrigerant tubes are sealably coupled in fluid receiving relation relative to the refrigerant distribution plate, and the refrigerant distribution plate is coupled in fluid receiving relation relative to the second source of the refrigerant; and

a refrigerant collection plate which is sealably mounted on the second end of the exterior container, and wherein the second end of each of the helical coil shaped refrigerant tubes are sealably coupled in fluid discharging relation relative to the refrigerant collection plate.

3. A heat exchanger as claimed in claim **1**, and wherein the respective refrigerant tubes when helically nested together are spaced from adjacent refrigerant tubes at a distance which lies in a range of about 1.2 to about 2 times the outside diametral dimension of the respective refrigerant tubes.

4. A heat exchange as claimed in claim **1**, and wherein the first source of the refrigerant is a low pressure refrigerant having a pressure of about 5 PSI[A] to about 315 PSI[A] which evaporates when the heat exchanger is used in a cooling operation, and the second source of the refrigerant is a high pressure refrigerant having a pressure of about 90 PSI[A] to about 750 PSI[A] which condenses when the heat exchanger is used in a cooling operation.

5. A heat exchanger as claimed in claim **4**, and wherein the low pressure refrigerant comprises ammonia, and the high pressure refrigerant is carbon dioxide.

6. A heat exchanger as claimed in claim **1**, and wherein the respective refrigerant tubes impart a substantially similar pressure drop, and an equal flow path of the second source of the refrigerant as the refrigerant travels between the first and second ends thereof.

7. A heat exchanger as claimed in claim **1**, and wherein the respective refrigerant tubes each have a predetermined helical coil diameter, and are either left-handed or right-handed in orientation, and wherein at least some of the helical coils located within the internal cavity are juxtaposed relative to other helical coils which have an opposite coil orientation.

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