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Nelson

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(54) **DIRECT EXPANSION AMMONIA REFRIGERATION SYSTEM AND A METHOD OF DIRECT EXPANSION AMMONIA REFRIGERATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 182 days.

This patent is subject to a terminal disclaimer.

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(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 12/156,980, filed on Jun. 6, 2008, now Pat. No. 7,958,738.

(51) **Int. Cl.**
F25B 15/00 (2006.01)

(52) **U.S. Cl.**
USPC **62/112**; 62/509

(58) **Field of Classification Search**
USPC 62/112, 498, 504, 509, 434; 165/104.26, 165/302; 122/366
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,196,504	A	4/1980	Eastman
4,280,337	A	7/1981	Kemp
4,577,468	A	3/1986	Nunn, Jr. et al.
4,586,344	A	5/1986	Lutz et al.
4,612,086	A	9/1986	Dominguez
4,825,661	A	5/1989	Holtzapple et al.
4,890,668	A	1/1990	Cima
4,903,761	A	2/1990	Cima
4,929,414	A	5/1990	Leonard et al.
5,189,885	A	3/1993	Ni
5,305,941	A	4/1994	Kent et al.
5,314,010	A	5/1994	Sakaya et al.
5,325,676	A	7/1994	Meckler
5,725,049	A	3/1998	Swanson et al.
6,018,958	A	2/2000	Lingelbach et al.
6,089,039	A	7/2000	Yamauchi
6,349,564	B1	2/2002	Lingelbach et al.
6,467,301	B1	10/2002	Lingelbach et al.
6,467,302	B1	10/2002	Lingelbach et al.
6,629,432	B1	10/2003	Critoph
2001/0027664	A1	10/2001	Ross
2002/0124993	A1	9/2002	Nakano
2006/0042274	A1	3/2006	Manole
2006/0243426	A1	11/2006	Hsu
2008/0125747	A1	5/2008	Prokop

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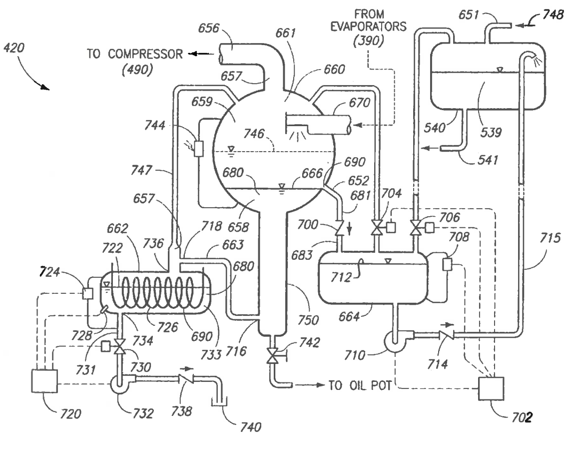
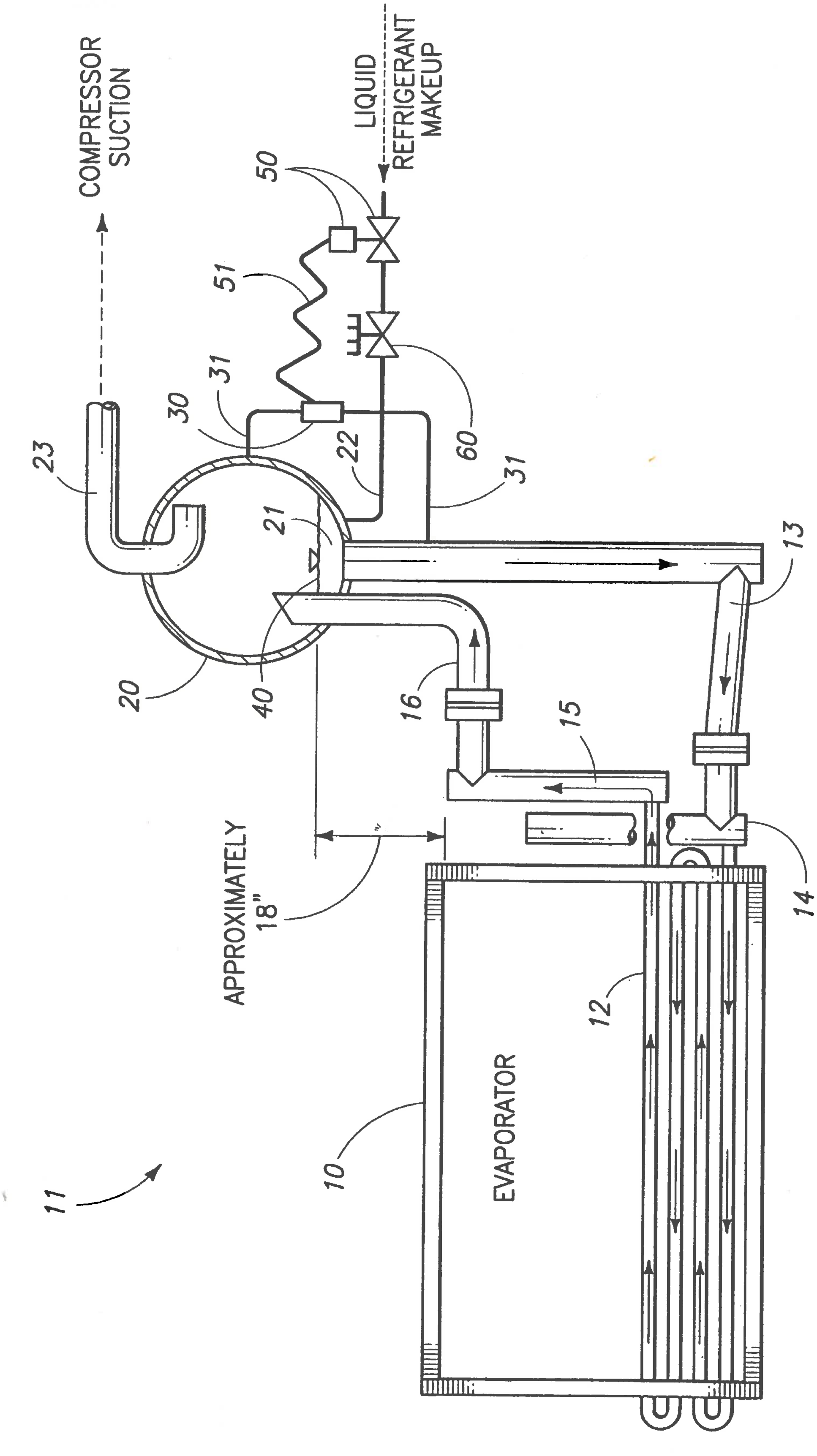
(57) **ABSTRACT**

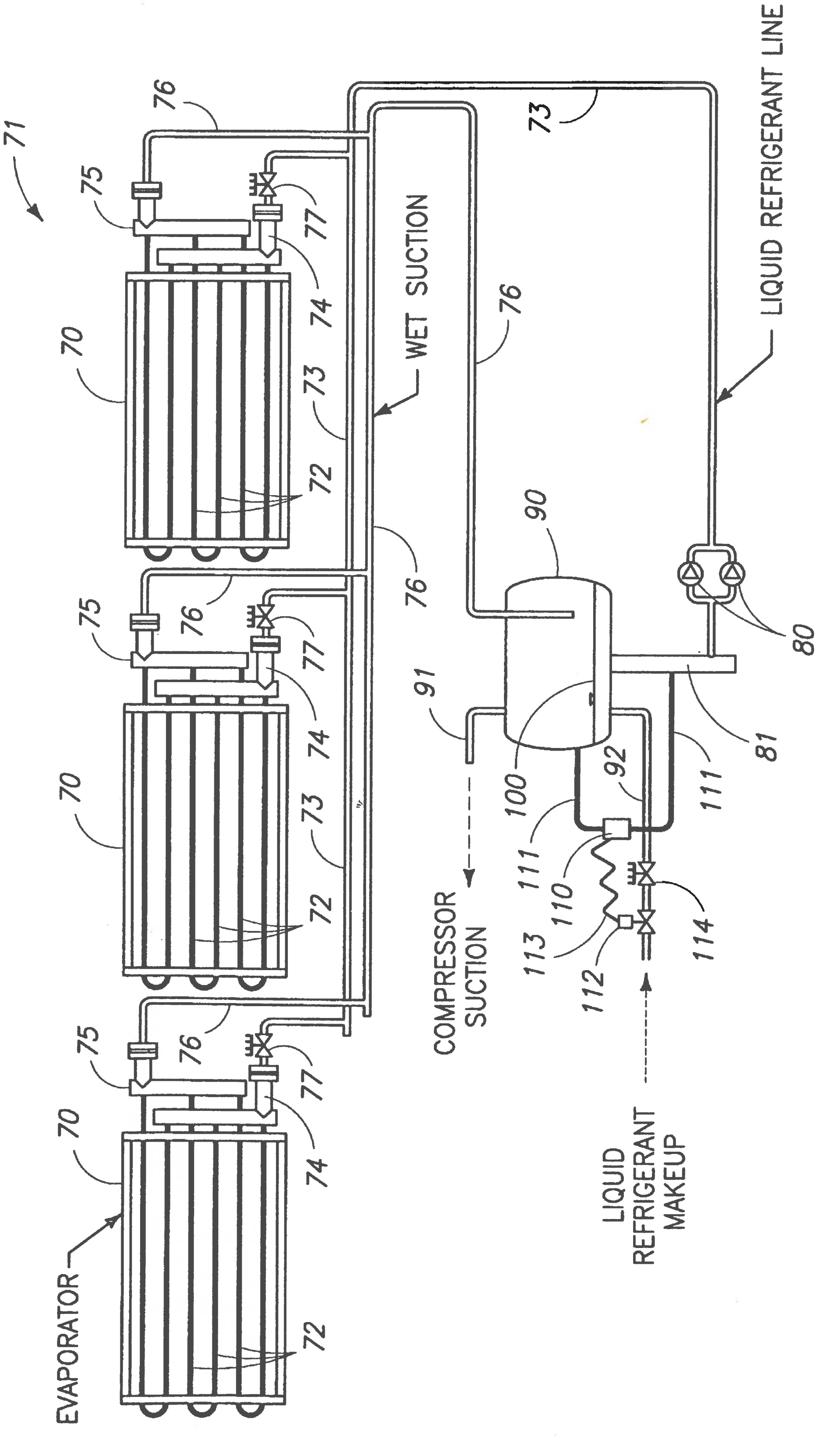
A direct expansion ammonia refrigeration system and a method of direct expansion ammonia refrigeration is described and which includes a source of liquid ammonia refrigerant which is delivered in fluid flowing relation to a plurality of evaporator tubes which incorporate wicking structures, and which through capillary action facilitated by the wicking structures are effective for drawing liquid ammonia refrigerant along the inside facing surface of the evaporator tubes so as to substantially reduce any stratified and/or wavy flow patterns of the liquid ammonia refrigerant within the evaporator tubes. The invention further includes a novel accumulator vessel and heat exchanger vessel which are coupled in fluid flowing relation relative to the direct expansion ammonia refrigeration system and which facilitate the removal of water from the ammonia refrigerant in order to enhance the operation of the direct expansion ammonia refrigeration system.

19 Claims, 13 Drawing Sheets



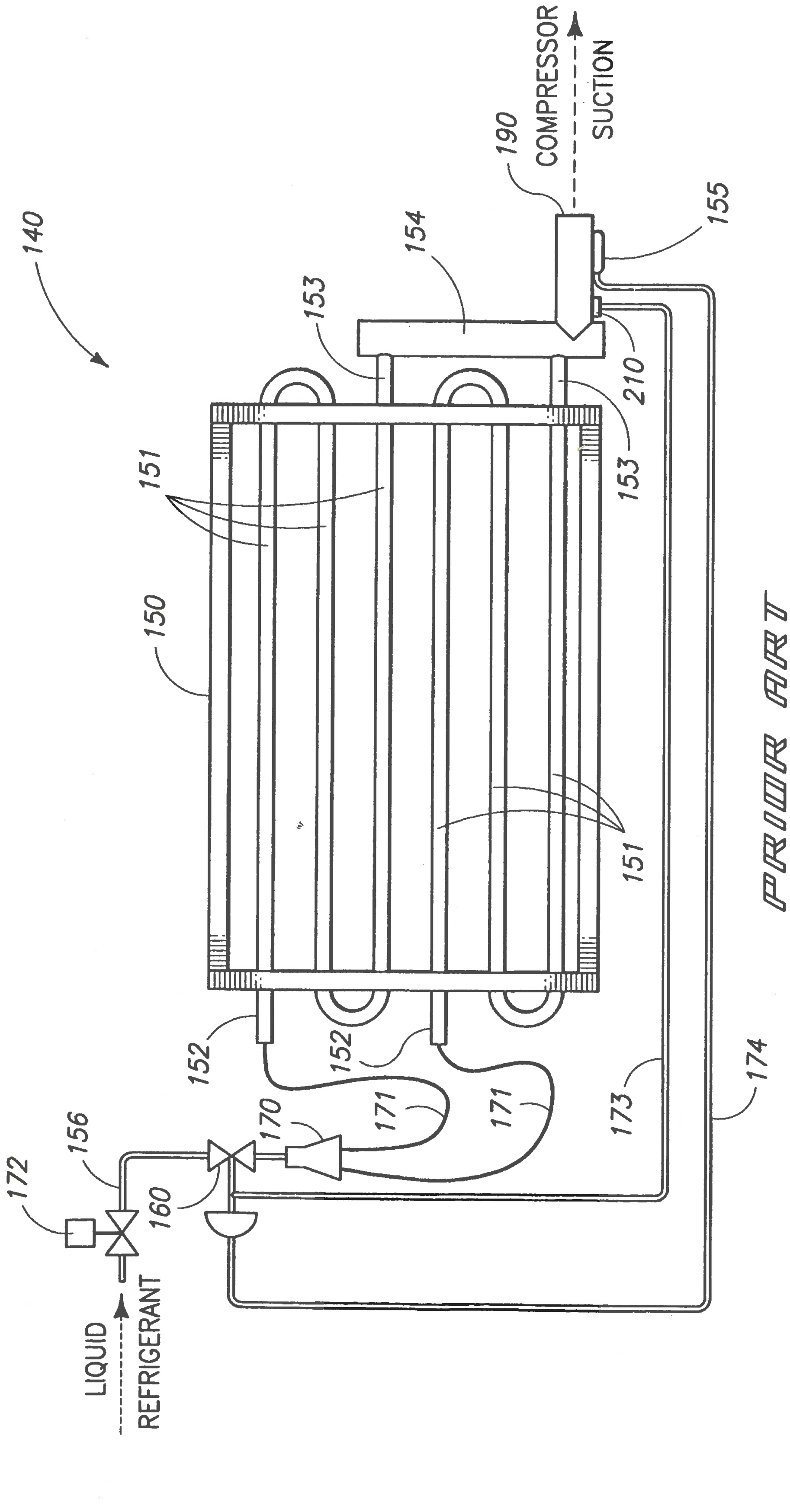


PRIOR ART
Fig 1



PRIOR ART

Fig. 2



PRIOR ART

FIG 3

FLOW PATTERNS DURING EVAPORATION IN A SMOOTH INSIDE DIAMETER HORIZONTAL EVAPORATOR TUBE

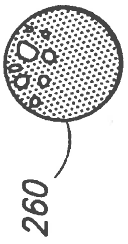


FIG 4A

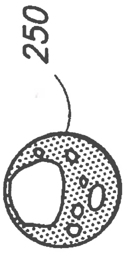


FIG 4B

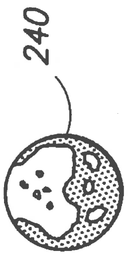


FIG 4C

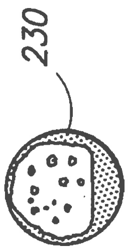


FIG 4D

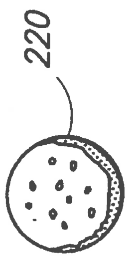
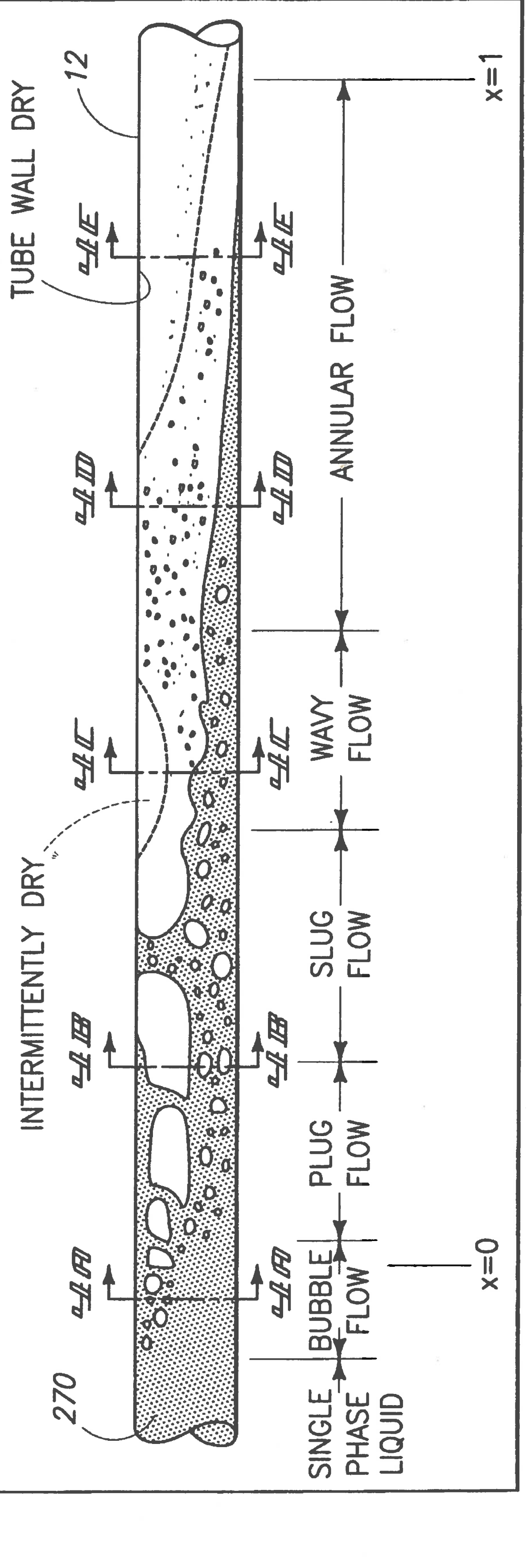
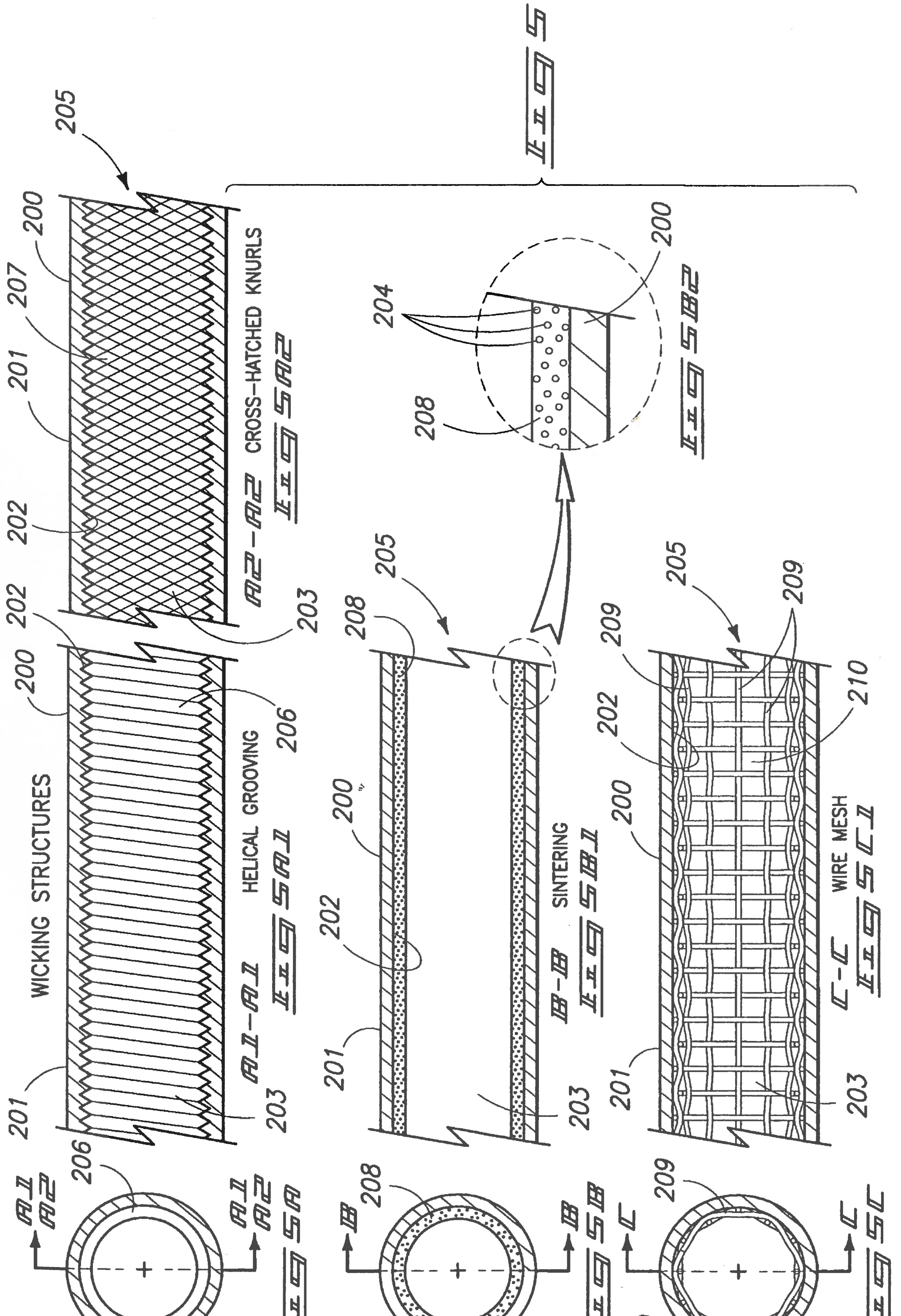


FIG 4E



PRIOR ART

FIG 4



WICKING STRUCTURES

Fig 5A

Fig 5A1 HELICAL GROOVING

Fig 5A2 CROSS-HATCHED KNURLS

Fig 5B

Fig 5B1 SINTERING

Fig 5B2

Fig 5C

Fig 5C1 WIRE MESH

Fig 5

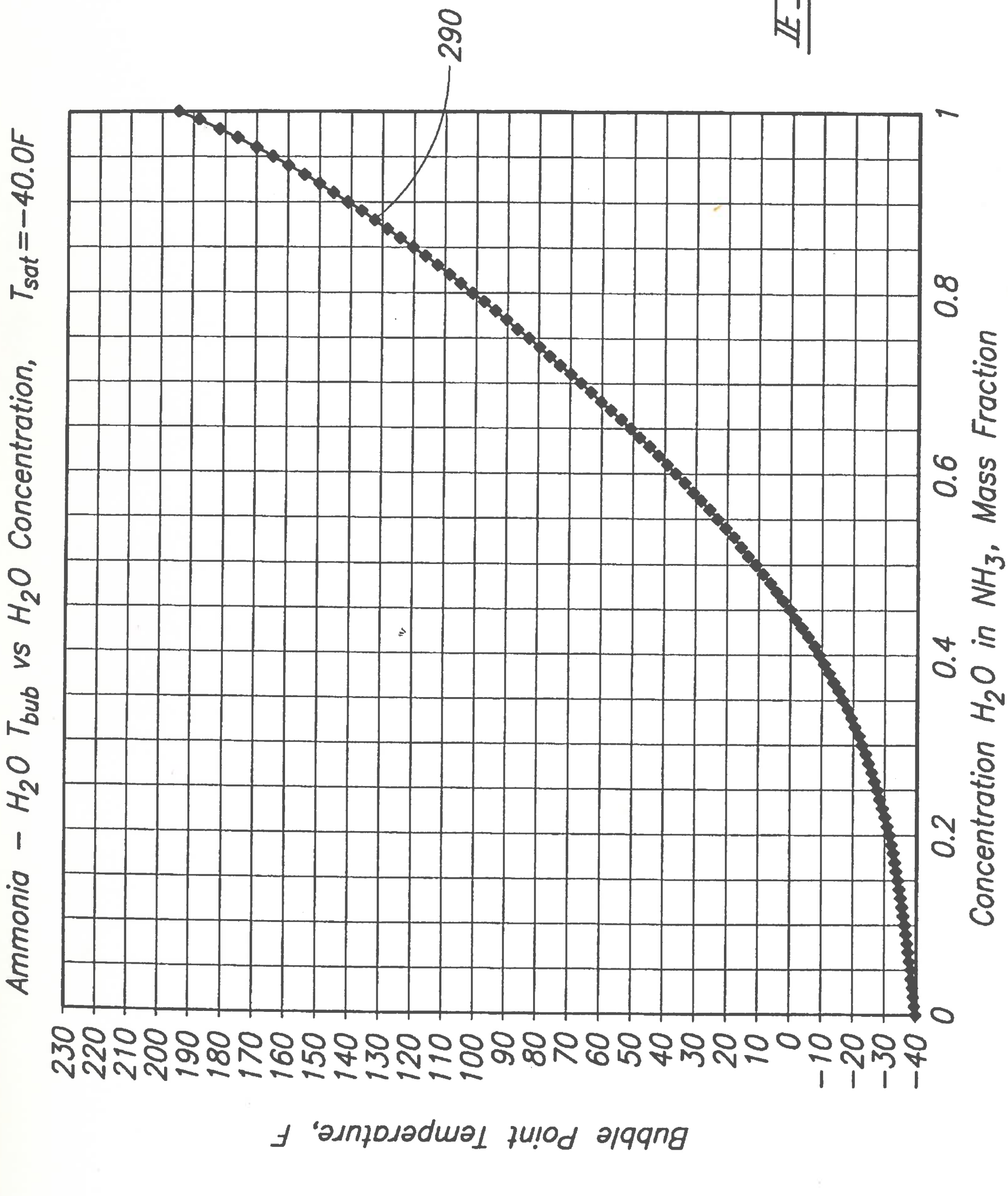
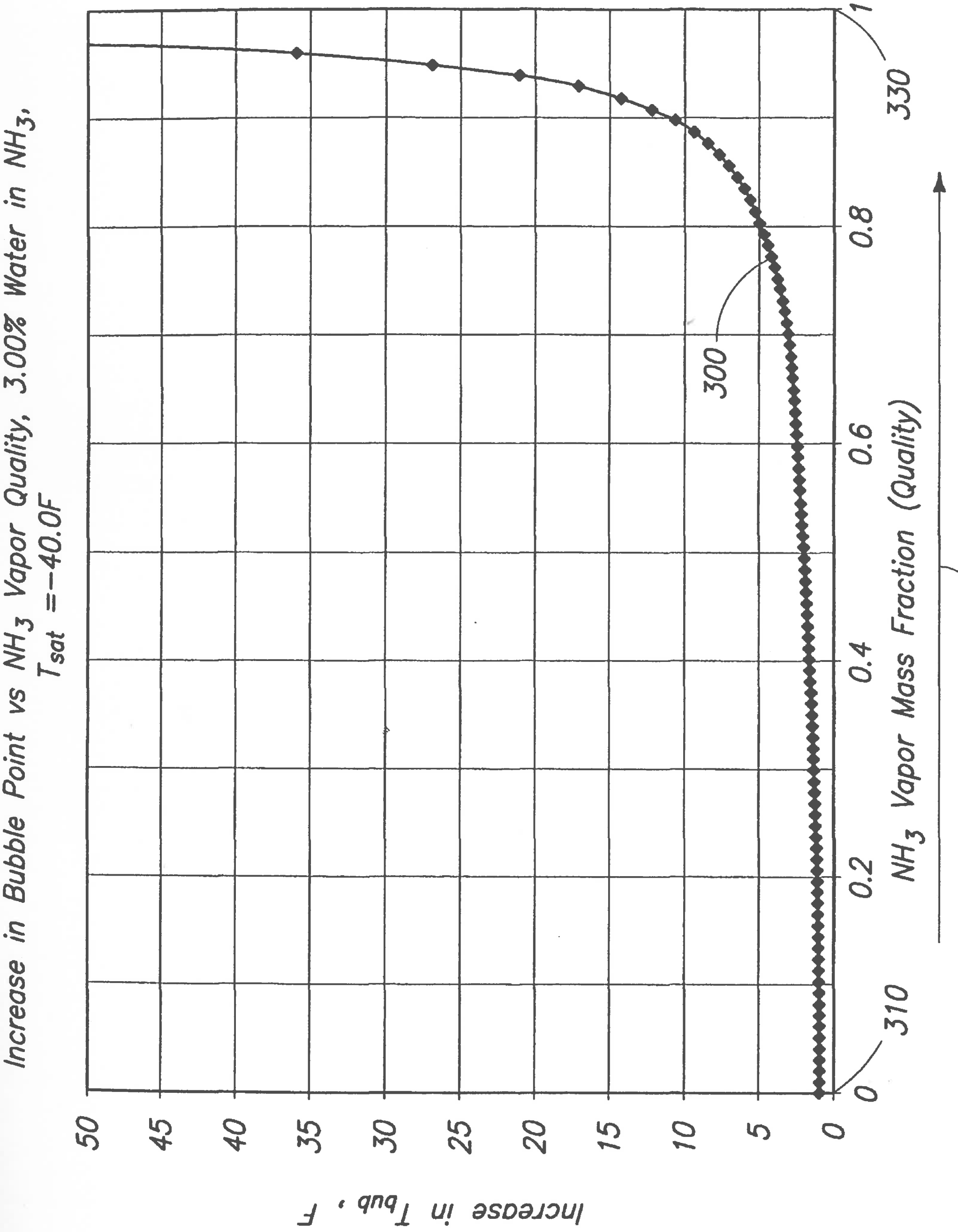

Ammonia – H2O Tbub vs H2O Concentration, Tsat=−40.0F
290
Bubble Point Temperature, F
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
Concentration H2O in NH3, Mass Fraction
0
0.2
0.4
0.6
0.8
1

Fig. 6



Increase in Bubble Point vs NH_3 Vapor Quality, 3.00% Water in NH_3,
T_{sat} =−40.0F
Increase in T_{bub}, F
50
45
40
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
NH_3 Vapor Mass Fraction (Quality)
300
310
320
330

FIG. 7

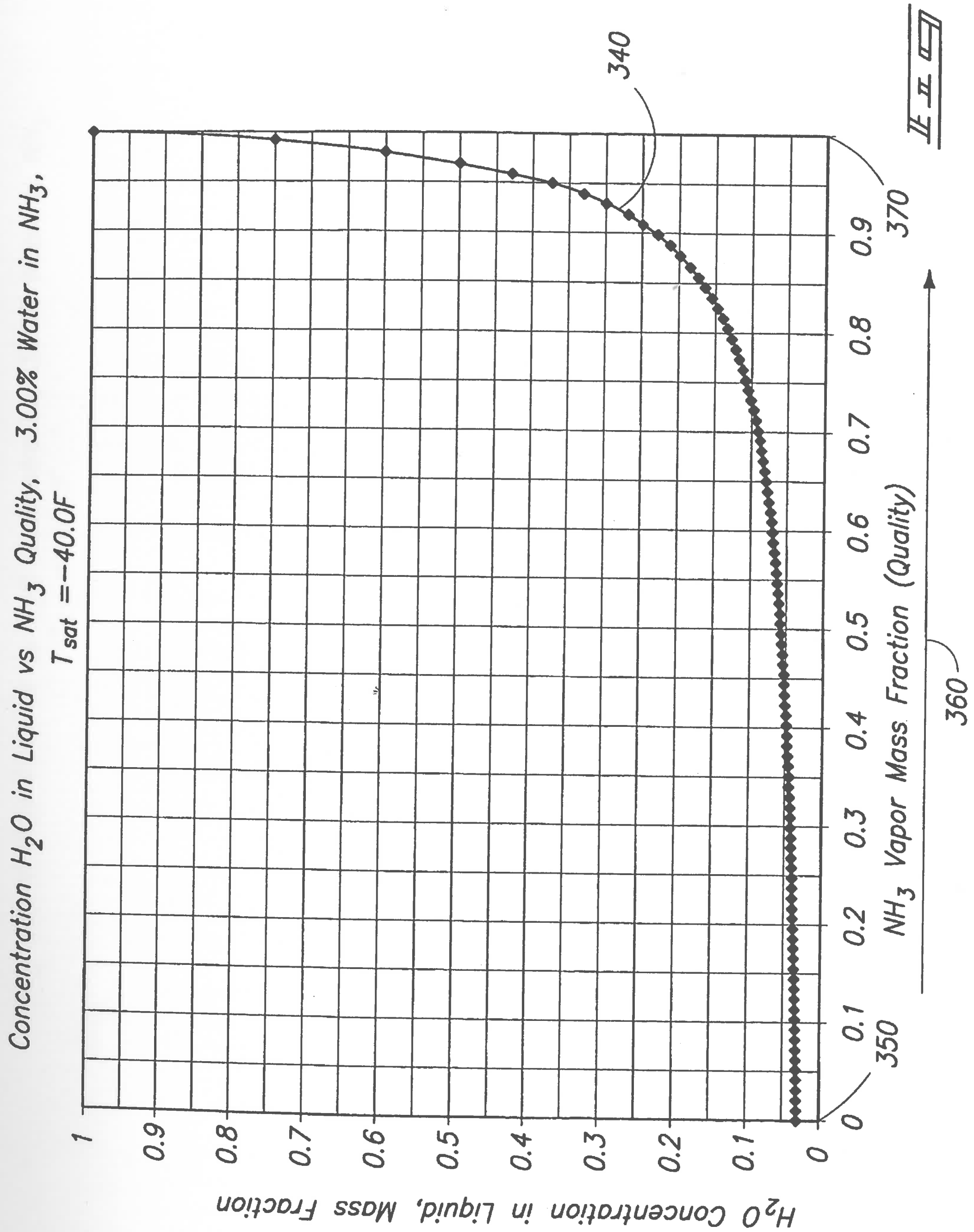

Concentration H_2O in Liquid vs NH_3 Quality, 3.00% Water in NH_3,
T_{sat} =-40.0F
340
370
350
360
H_2O Concentration in Liquid, Mass Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NH_3 Vapor Mass Fraction (Quality)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

FIG. 8

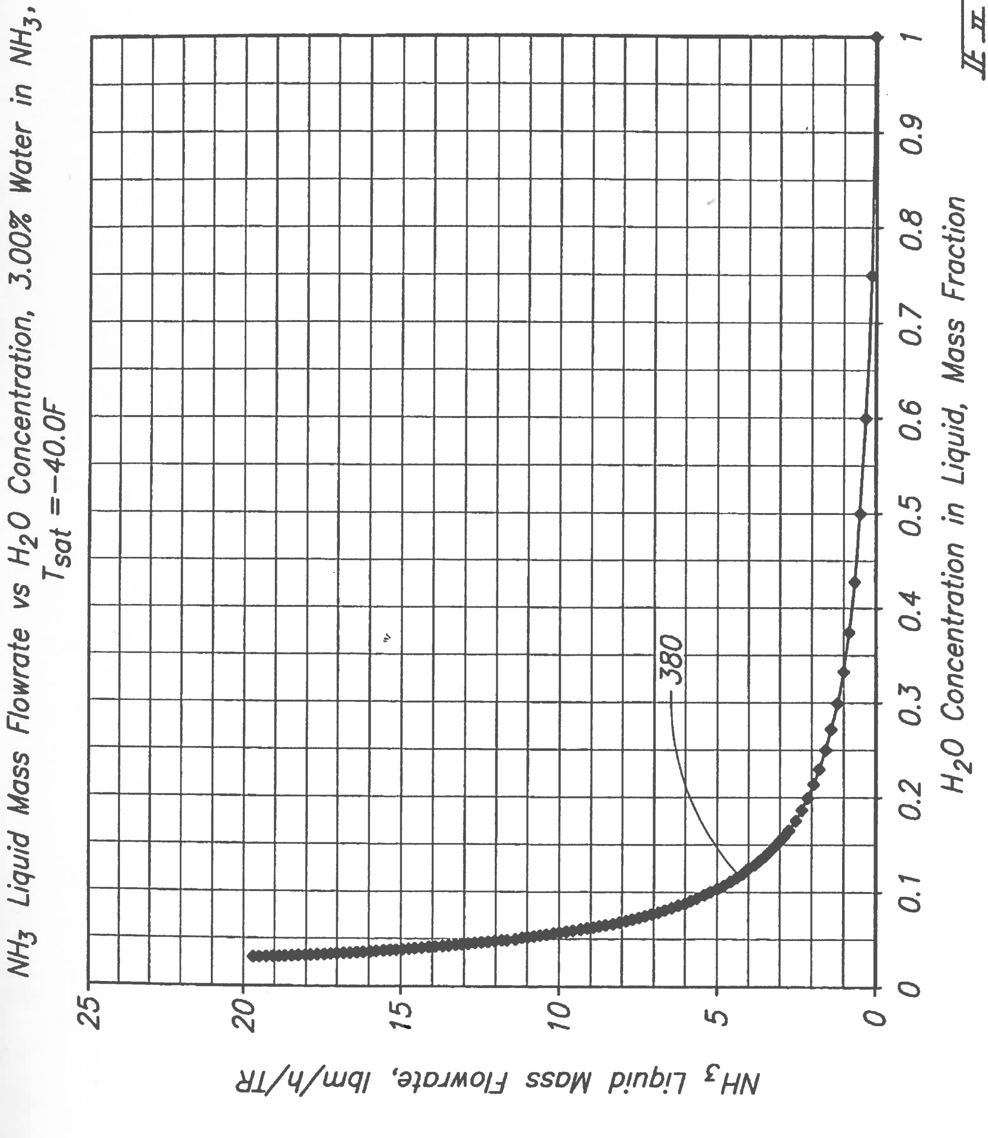

NH$_3$ Liquid Mass Flowrate vs H$_2$O Concentration, 3.00% Water in NH$_3$,
T$_{sat}$ =−40.0F
NH$_3$ Liquid Mass Flowrate, lbm/h/TR
25
20
15
10
5
0
H$_2$O Concentration in Liquid, Mass Fraction
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
380

FIG. 9

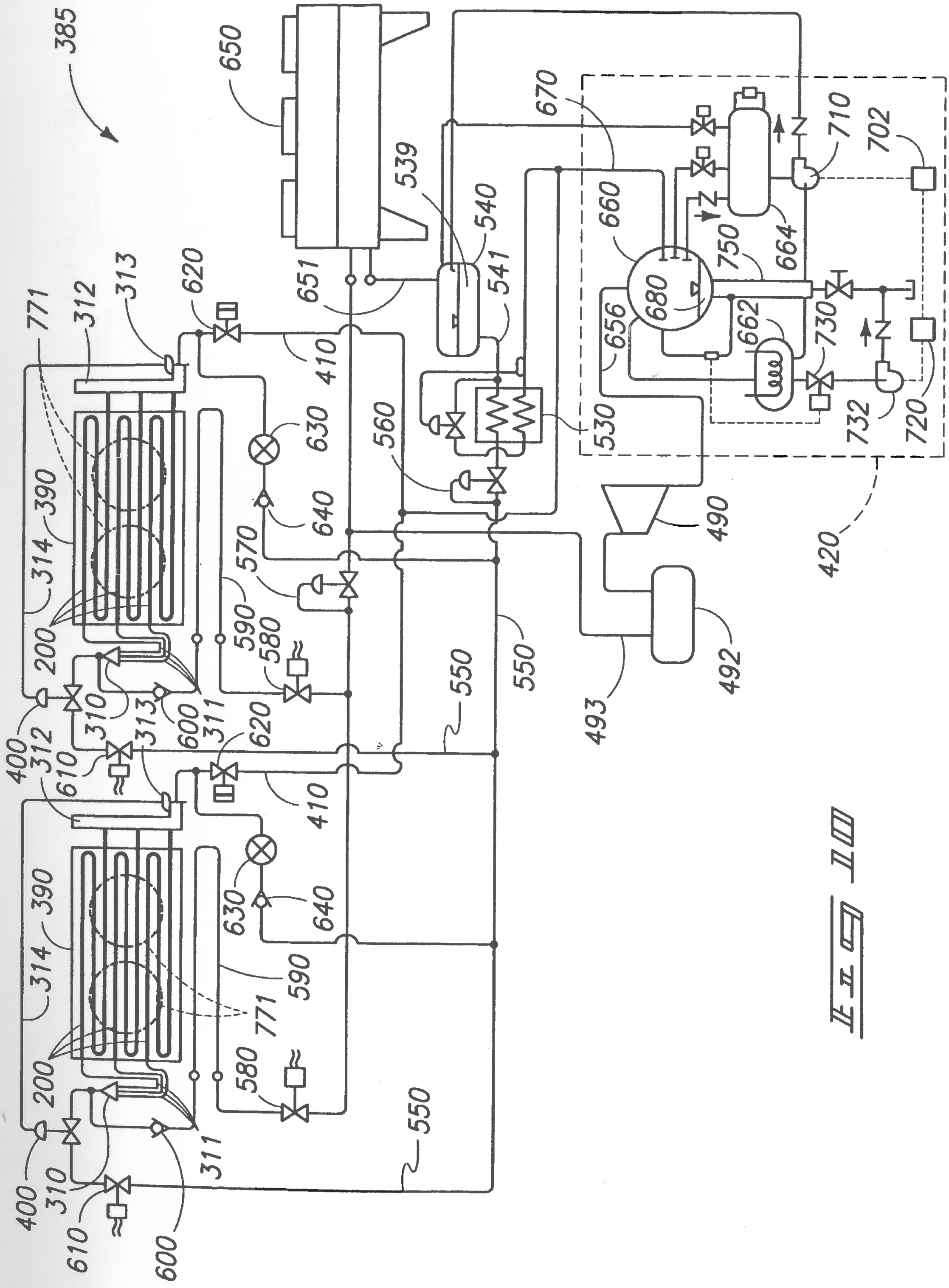

385
650
651
539
540
541
670
660
664
710
702
750
680
656
662
730
732
720
530
420
490
492
493
560
570
580
590
550
620
410
630
640
771
312
313
314
390
200
310
311
400
600
610

FIG. 10

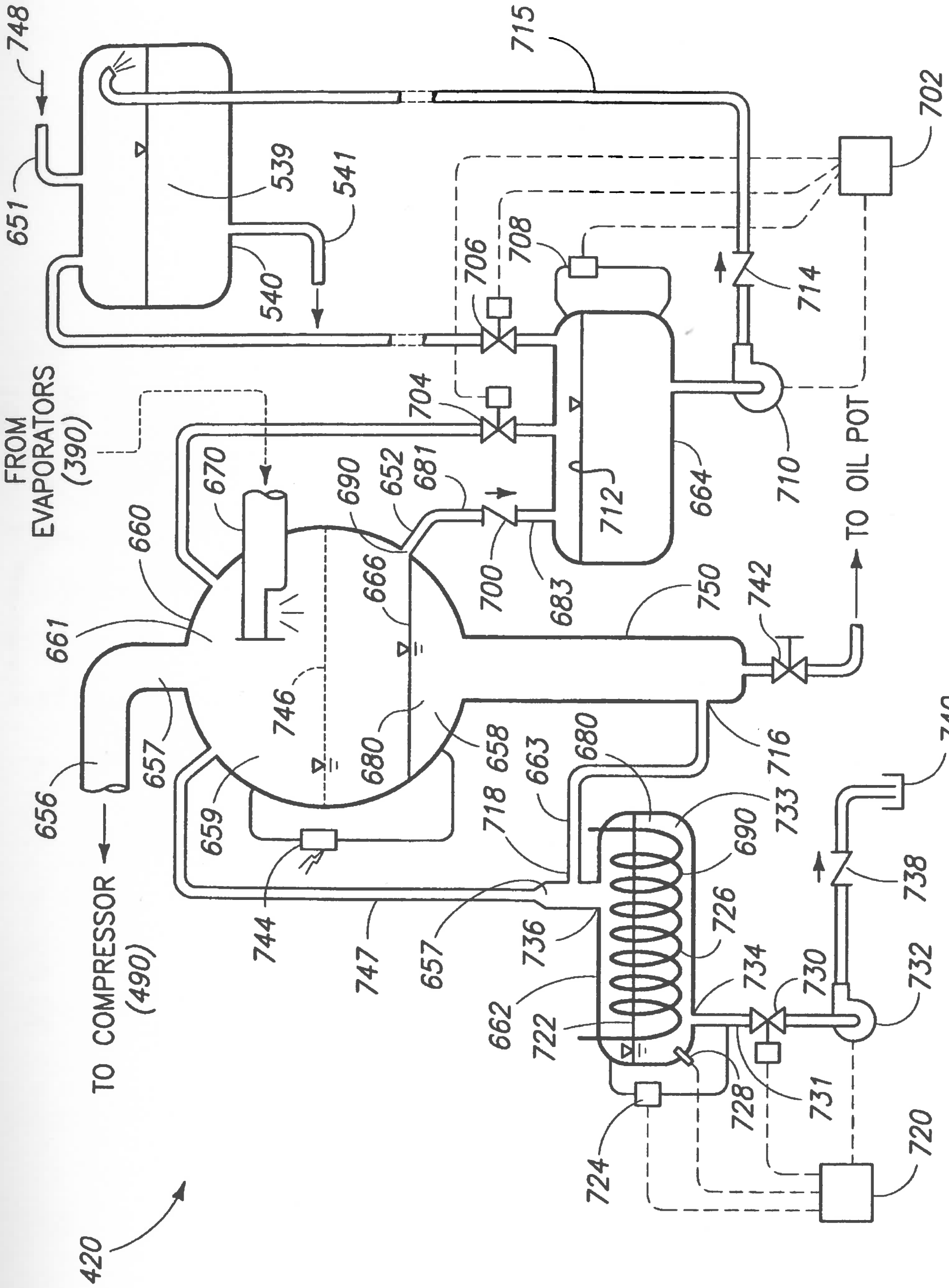

748
651
539
541
540
715
702
706
708
714
704
FROM EVAPORATORS (390)
670
690
652
681
660
666
700
683
712
664
710
TO OIL POT
661
750
742
746
656
657
680
658
718
663
716
733
740
659
690
744
TO COMPRESSOR (490)
747
657
736
726
738
734
730
732
662
722
731
728
720
724
420

Fig. 11

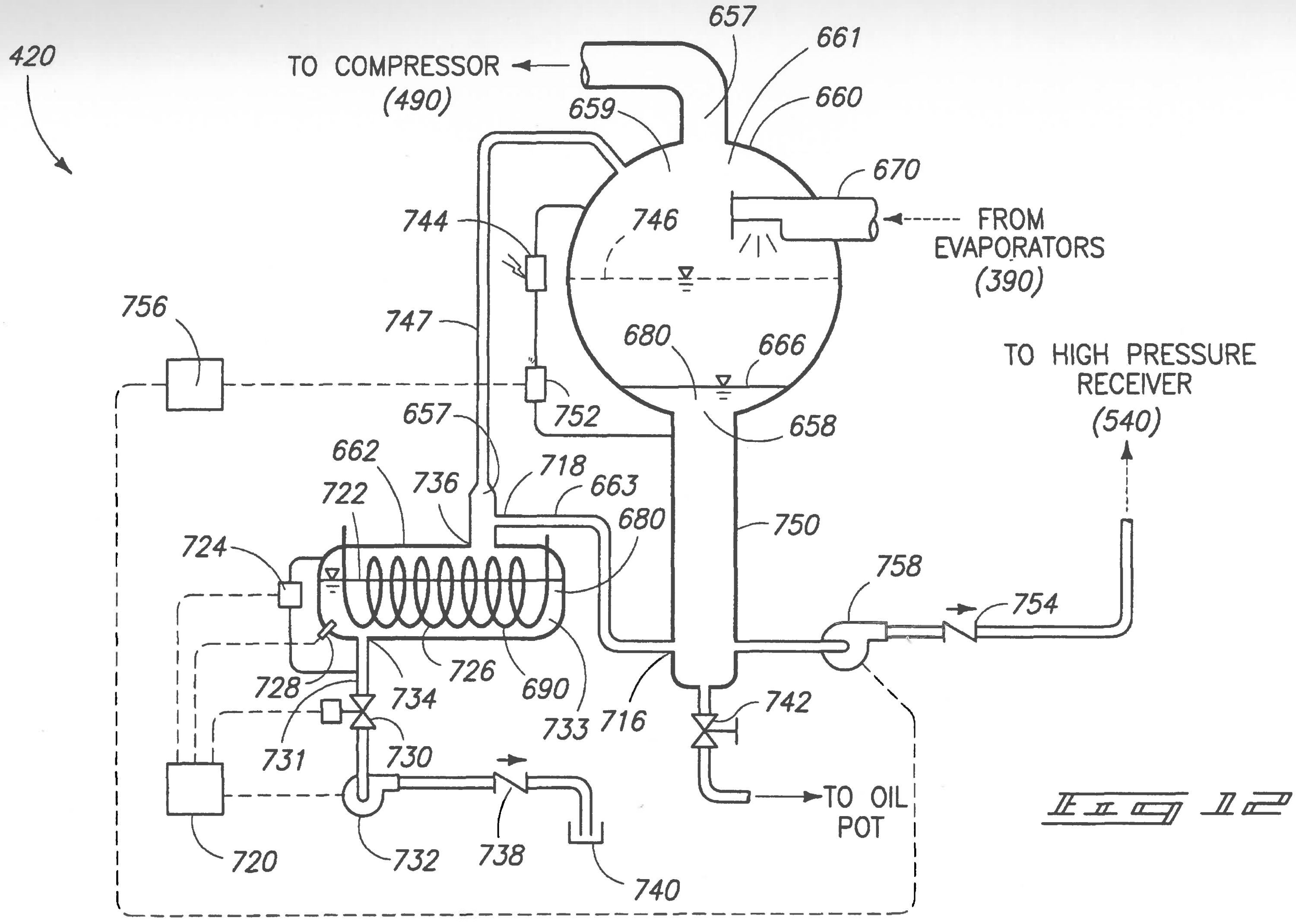
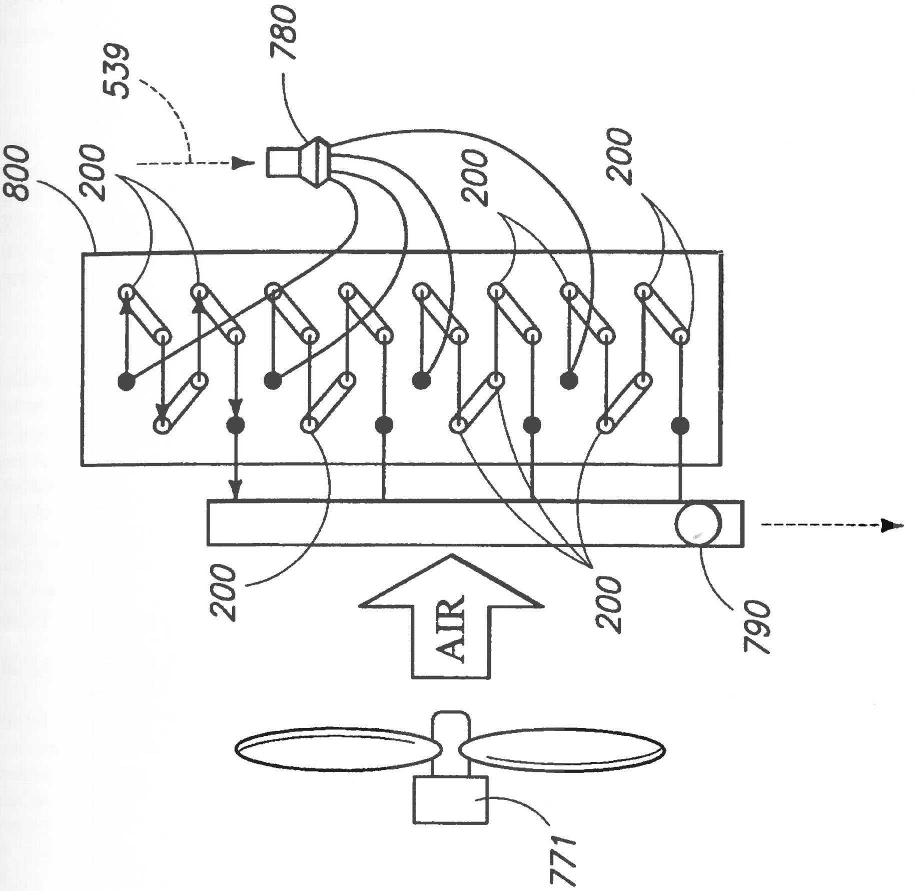
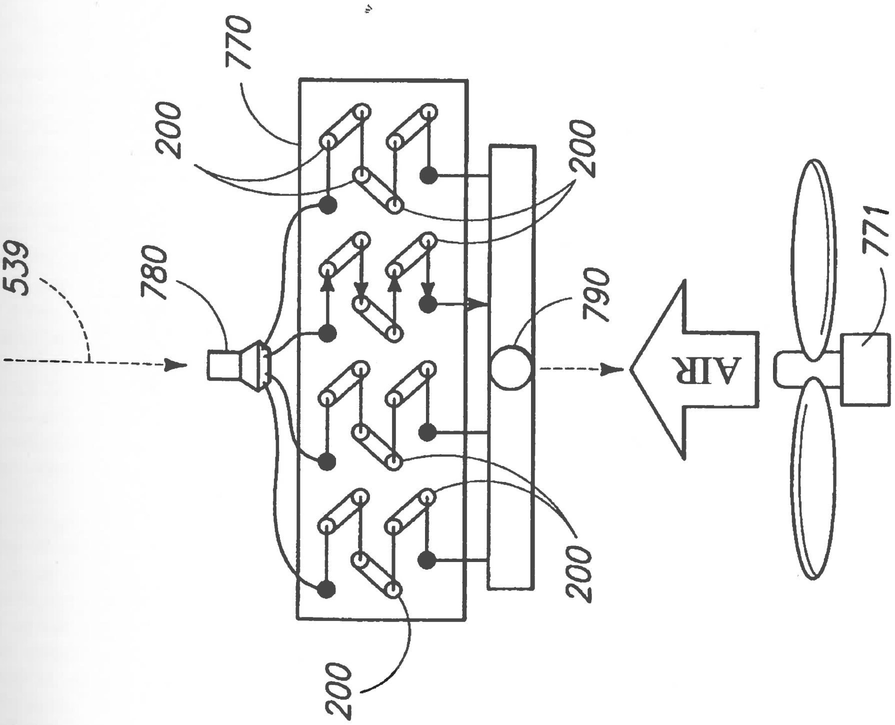

420
TO COMPRESSOR
(490)
657
661
660
659
670
FROM
EVAPORATORS
(390)
744
746
756
747
680
666
TO HIGH PRESSURE
RECEIVER
(540)
752
657
658
662
718
663
722
736
680
750
724
758
754
728
734
726
690
742
733
716
731
730
720
732
738
740
TO OIL
POT

FIG. 12



800
200
539
780
200
200
AIR
200
200
790
771

FIG. 14



539
780
200
770
200
790
AIR
771
200
200

FIG. 13

DIRECT EXPANSION AMMONIA REFRIGERATION SYSTEM AND A METHOD OF DIRECT EXPANSION AMMONIA REFRIGERATION

RELATED PATENT DATA

This application is a continuation of U.S. patent application Ser. No. 12/156,980, filed on Jun. 6, 2008 now U.S. Pat. No. 7,958,738, and which is entitled "Direct Expansion Ammonia Refrigeration System and a Method of Direct Expansion Ammonia Refrigeration."

TECHNICAL FIELD

The present invention relates to a direct expansion ammonia refrigeration system and a method of direct expansion ammonia refrigeration system, and more specifically to a direct expansion ammonia refrigeration system employing evaporator tubes using a novel wicking structure, and an arrangement whereby any ammonia-water solution exiting an evaporator tube may be captured, and effectively removed from the direct expansion ammonia refrigeration system before it reaches and potentially damages a compressor which is utilized with the same system.

BACKGROUND OF THE INVENTION

The beneficial effects of employing ammonia as a working refrigerant in vapor compression refrigeration systems has been known since the late 19th century. Those skilled in the art have recognized that ammonia has many advantages when utilized as a refrigerant. As a first matter, it has a high critical temperature; and secondly, a low triple point temperature which allows it to be applied over a wide range of applications. These applications include air conditioning applications where the air is maintained at temperatures greater than about 45 degrees F., to low temperature refrigeration applications where the air temperature must be maintained at temperatures at or below −40 degrees F. Ammonia has a latent heat of vaporization which is considered high and which reduces the mass flow required for any given refrigeration load. The direct result of this latent heat of vaporization is that for a given refrigeration load, the resulting liquid line sizes are relatively small. Still further, other thermodynamic and thermophysical properties of ammonia result in good heat transfer coefficients. This results in efficient and compact heat exchanger designs being employed in various applications.

Ammonia is also considered to be an environmentally friendly, or "green" refrigerant since it occurs in nature and has no known capacity for depleting ozone in the atmosphere. It further has no apparent global warming potential. Those skilled in the art recognize that ammonia is used widely in a number of industry segments and in various applications. Ammonia is relatively easy to produce and is low in cost as compared to other halo-carbon refrigerants now being employed.

While ammonia has been known for a long period of time and has many advantages, it also has some disadvantages which have detracted from its usefulness. Chief among its shortcomings is that ammonia is toxic in high concentrations; is an irritant in low concentrations; and further has a very pungent order when released. Still further, ammonia is flammable in a narrow range of concentrations with air. Another serious shortcoming with ammonia is that ammonia has a significant affinity for water. Ammonia readily reacts with any water which may inadvertently get introduced to a refrigeration system and thereafter holds the water tightly in solution. In the prior art ammonia refrigeration systems utilized heretofore, water has always been considered a contaminant. It has been known that it is extremely difficult to keep water out of a prior art ammonia refrigeration system. Unfortunately, even in small amounts, an aqueous ammonia refrigerant can significantly increase the boiling point of the refrigerant mixture resulting in reduced refrigeration system performance, and increased operating costs. Typically, the presence of only a small amount of water in the prior art ammonia refrigeration system, employed heretofore, will typically cause an expansion valve control function to fail. If this failure is left unintended the ever increasing concentration of water in the refrigerant increases the boiling point of the ammonia-water concentration until the expansion valve controller is no longer able to sense the correct amount of superheat in any resulting refrigerant vapor. If left uncorrected, this same ammonia-water refrigerant can ultimately irreparably damage a compressor employed with the same refrigeration system.

Heretofore, industrial ammonia evaporators employed with prior art refrigeration systems have been typically fed with liquid refrigerant in one of several ways. These ways have included gravity flooding; liquid overfeed; and direct or dry expansion. With respect to both prior art gravity flooding, and liquid overfeed ammonia refrigeration systems, these systems require relatively large inventories of liquid ammonia refrigerant circulating between various vessels, and the evaporators employed with these systems. On the other hand, direct expansion ammonia refrigeration systems operate with the smallest amount of ammonia refrigerant inventory possible. In view of the aforementioned advantages, and disadvantages, of ammonia refrigerant discussed, above, direct expansion ammonia refrigeration systems have become quite attractive, at a number of different levels, for the owners and operators of these same systems. For example, the ability to operate with a low ammonia refrigerant charge in a refrigeration system is desirable because, as a first matter, this reduces the cost of manufacturing these same systems by allowing for the elimination of pressure vessels, pumps and the reduction of liquid line sizes. Secondly, direct expansion ammonia refrigeration systems are attractive because of their reduced risk of fire or explosion. Still further, they present reduced risks should an ammonia leak occur. Additionally, because of these reduced risks of system damage or worker injury because of the smaller amount of ammonia refrigerant being used, owners of such systems may experience a lower insurance rate and further reduced EPA and OSHA health and safety requirements for installing and operating such systems.

Notwithstanding these many advantages, an efficient and highly effective direct expansion ammonia refrigeration system has proved elusive to designers. Prior art direct expansion ammonia refrigeration systems have continued to suffer from poor evaporator performance caused by undesirable two phase flow patterns of the ammonia refrigerant in the evaporator tubes, from malfunctioning thermostatic expansion valves, and the consequent damage to compressors resulting from the return of ammonia-water solutions to the compressors caused by the effects noted, above. Consequently, owners and operators of prior art ammonia refrigeration systems have had to live, heretofore, with larger ammonia refrigerant inventories associated with gravity flooded and pump recirculated arrangements as will be described in greater detail hereinafter.

OBJECTS AND SUMMARY OF THE INVENTION

Therefore, a first aspect of the present invention relates to a direct expansion ammonia refrigeration system which includes a source of liquid ammonia refrigerant; and an evaporator tube coupled in fluid receiving relation relative to the source of liquid ammonia refrigerant, and which has an inside facing surface having a wicking structure, and wherein capillary action, facilitated by the wicking structure, draws the liquid ammonia refrigerant along the inside facing surface of the evaporator tube so as to substantially reduce any stratified and/or wavy flow patterns of the liquid ammonia refrigerant within the evaporator tube.

Another aspect of the present invention relates to a direct expansion ammonia refrigeration system which includes a source of liquid ammonia refrigerant; a direct expansion ammonia evaporator; a compressor which is coupled in fluid flowing relation relative to the source of liquid ammonia refrigerant, and which provides the liquid ammonia refrigerant to the direct expansion ammonia evaporator; an accumulator vessel defining an internal cavity having a liquid region, and a vapor region, and wherein the vapor region is coupled in fluid receiving relation relative to the direct expansion ammonia evaporator, and in fluid delivering relation relative to the compressor, and wherein the liquid region contains aqueous liquid ammonia received from the evaporator; and a heat exchanger vessel coupled in fluid receiving relation relative to the liquid region of the accumulator vessel, and in fluid delivering relation relative to the vapor region of the accumulator vessel, and wherein the heat exchanger vessel includes a heating element which vaporizes the aqueous liquid ammonia so as to deliver substantially dry ammonia vapor to the vapor region of the accumulator vessel, and wherein the substantially dry ammonia vapor is subsequently delivered to the compressor.

Still another aspect of the present invention relates to a direct expansion ammonia refrigeration system which includes a source of liquid ammonia refrigerant; a direct expansion ammonia evaporator which has a plurality of evaporator tubes, and which are coupled in fluid flowing relation relative to the source of liquid ammonia refrigerant; a compressor which provides the source of liquid ammonia refrigerant under pressure to the direct expansion ammonia evaporator; an accumulator vessel defining an internal cavity which has a liquid region; and a vapor region, which, is coupled in downstream fluid flowing relation relative to the direct expansion ammonia evaporator, and which is further coupled in upstream fluid flowing relation relative to the compressor, and wherein the liquid region contains aqueous liquid ammonia received from the evaporator, and wherein the liquid and vapor regions of the accumulator vessel are defined, one relative to the other, by an aqueous liquid ammonia level, and wherein the accumulator vessel has a minimum aqueous liquid ammonia level, and a maximum aqueous liquid ammonia level; a heat exchanger vessel coupled in downstream fluid flowing relation relative to the liquid region of the accumulator vessel, and which is further coupled in upstream fluid flowing relation relative to the vapor region of the accumulator vessel, and wherein the heat exchanger vessel comprises a heating element which vaporizes at least some of the aqueous liquid ammonia so as to deliver substantially dry ammonia vapor to the vapor region of the accumulator vessel, and a remaining acceptably concentrated aqueous ammonia byproduct, and wherein the substantially dry ammonia vapor is subsequently delivered to the compressor; a first fluid conduit having a first end, and a second end, and wherein the first end is coupled in fluid flowing relation relative to the liquid region of the accumulator vessel, and the second end is coupled in fluid flowing relation relative to the heat exchanger vessel, and wherein the first end is positioned at an elevation below the heat exchanger vessel, and the second end is positioned at an elevation above the heat exchanger vessel; a liquid transfer vessel coupled in fluid flowing relation relative to the accumulator vessel, and which regulates the aqueous liquid ammonia level of the accumulator vessel; a second fluid conduit having a first end coupled in fluid flowing relation relative to the accumulator vessel, and a second end coupled in fluid flowing relation relative to the liquid transfer vessel, and wherein the first end is positioned above the minimum aqueous liquid ammonia level, and below the maximum aqueous liquid ammonia level of the accumulator vessel; a high pressure receiver vessel which is coupled in fluid flowing relation relative to the liquid transfer vessel; a plurality of solenoid valves positioned in fluid metering relation therebetween the accumulator vessel, and the liquid transfer vessel, and between the liquid transfer vessel and the high pressure receiver; and a controller for controlling the operation of the plurality of solenoid valves so as to regulate the aqueous liquid ammonia level of the accumulator vessel.

Yet still another aspect of the present invention relates to a direct expansion ammonia refrigerant system which includes a source of a substantially non-aqueous liquid ammonia refrigerant; a direct expansion ammonia evaporator having a plurality of evaporator tubes coupled in sequential gravity-feeding relation one relative to the others, and in fluid receiving relation relative to the source of liquid ammonia refrigerant, and wherein each of the evaporator tubes has an inside facing surface which defines individual refrigerant passageways, and wherein the inside facing surface of at least one of the plurality evaporator tubes incorporates a wicking structure within the refrigerant passageway, and which, by capillary action, effectively draws, at least in part, the liquid ammonia refrigerant entering the refrigerant passageway along the inside facing surface so as to reduce any stratified and/or wavy flow patterns of the liquid ammonia refrigerant as it moves within the at least one of the plurality of evaporator tubes, and wherein the substantially non-aqueous liquid ammonia refrigerant leaves the respective evaporator tubes as substantially aqueous liquid ammonia and/or ammonia vapor; an accumulator vessel defining an internal cavity, and which has a liquid region, and a vapor region, and wherein the vapor region further defines a fluid intake which is coupled in fluid receiving relation relative to the plurality of evaporator tubes, and wherein the liquid region receives and contains the aqueous liquid ammonia received from the plurality of evaporator tubes; a heat exchanger vessel coupled in fluid receiving relation relative to the liquid region of the accumulator vessel, and is further coupled in fluid delivering relation relative to the vapor region of the accumulator vessel, and wherein the heat exchanger vessel includes a heating element which, when energized, vaporizes the aqueous liquid ammonia so as to deliver a substantially dry ammonia vapor to the vapor region of the accumulator vessel, and produce an acceptably concentrated aqueous ammonia byproduct; and a compressor coupled in fluid receiving relation relative to the vapor region of the accumulator vessel, and in fluid delivering relation relative to the plurality of evaporator tubes, and wherein the substantially dry ammonia vapor from the vapor region of the accumulator vessel is delivered to the compressor for conversion back to a substantially non-aqueous liquid ammonia refrigerant, and wherein the compressor provides the source of the substantially non-aqueous liquid ammonia refrigerant to the direct expansion ammonia evaporator.

Moreover, another aspect of the present invention relates to a method of direct expansion ammonia refrigeration which includes the steps of providing a source of a substantially non-aqueous liquid ammonia refrigerant; providing a liquid ammonia expansion evaporator which has a plurality of evaporator tubes coupled in fluid receiving relation relative to the source of refrigerant, and wherein each of the plurality of evaporator tubes has an inside facing surface which has a wicking structure; and drawing the liquid ammonia refrigerant up onto the inside facing surface of the evaporator tube by capillary action by employing the wicking structure.

Yet another aspect of the present invention relates to a method of direct expansion ammonia refrigeration which includes the steps of providing a source of a substantially non-aqueous liquid ammonia; providing a liquid ammonia expansion evaporator; supplying the source of substantially non-aqueous liquid ammonia to the liquid ammonia expansion evaporator; providing a compressor coupled in upstream fluid flowing relation relative to the liquid ammonia expansion evaporator, and in downstream fluid flowing relation relative to the source of the substantially non-aqueous liquid ammonia; providing an accumulator vessel defining an internal cavity with a liquid region and a vapor region, and wherein the vapor region is coupled in downstream fluid flowing relation relative to the direct expansion ammonia evaporator, and is further coupled in upstream fluid flowing relation relative to the compressor; providing a heat exchanger vessel coupled in downstream fluid flowing relation relative to the liquid region of the accumulator vessel, and in upstream fluid flowing relation relative to the vapor region of the accumulator vessel, and wherein the heat exchanger vessel further includes a heating element; collecting any aqueous liquid ammonia and any ammonia vapor from the liquid ammonia expansion evaporator into the accumulator vessel, and wherein the ammonia vapor collects in the vapor region of the accumulator vessel, and the aqueous liquid ammonia collects in the liquid region of the accumulator vessel; transferring the aqueous liquid ammonia from the liquid region of the accumulator vessel to the heat exchanger vessel; heating the aqueous liquid ammonia in the heat exchanger vessel to vaporize at least some of the liquid ammonia, and producing a substantially dry ammonia vapor, while leaving an acceptably concentrated aqueous ammonia byproduct in the heat exchanger vessel; returning the substantially dry vaporized ammonia to the vapor region of the accumulator vessel; and delivering the substantially dry vaporized ammonia from the vapor region of the accumulator vessel to the compressor.

Still another aspect of the present invention relates to a method of direct expansion ammonia refrigeration which includes the steps of a) providing a source of a substantially non-aqueous liquid ammonia refrigerant; b) providing a liquid ammonia expansion evaporator, which has a plurality of evaporator tubes coupled in fluid flowing relation relative to the source of the substantially non-aqueous liquid ammonia refrigerant, and wherein each of the plurality of evaporator tubes has an inside facing surface which has a wicking structure; c) supplying the substantially non-aqueous liquid ammonia refrigerant to the plurality of evaporator tubes; d) drawing the substantially non-aqueous liquid ammonia refrigerant up onto the inside facing surface of the respective evaporator tubes with capillary action which is facilitated by the wicking structure; e) boiling the substantially non-aqueous liquid ammonia refrigerant within the respective evaporator tubes to produce aqueous liquid ammonia refrigerant and/or ammonia refrigerant vapor; f) providing a compressor coupled in upstream fluid flowing relation relative to the liquid ammonia expansion evaporator, and which supplies the substantially non-aqueous liquid ammonia refrigerant to the plurality of evaporator tubes; g) providing an accumulator vessel defining an internal cavity with a liquid region and a vapor region, and wherein the vapor region is coupled in downstream fluid flowing relation relative to the direct expansion ammonia evaporator, and is further coupled in upstream fluid flowing relation relative to the compressor; h) providing a heat exchanger vessel coupled in fluid receiving relation relative to the liquid region of the accumulator vessel, and which is further coupled in fluid delivering relation relative to the vapor region of the accumulator vessel, and wherein the heat exchanger vessel includes a heating element; i) collecting any aqueous liquid ammonia and/or any ammonia vapor from the liquid ammonia expansion evaporator into the accumulator vessel, and wherein the ammonia vapor collects in the vapor region of the accumulator vessel, and the aqueous liquid ammonia collects in the liquid region of the accumulator vessel; j) transferring the aqueous liquid ammonia from the liquid region of the accumulator vessel to the heat exchanger vessel; k) energizing the heating element so as to heat the aqueous liquid ammonia in the heat exchanger vessel and to vaporize at least some of the liquid ammonia to form substantially dry ammonia vapor while leaving an acceptably concentrated aqueous ammonia liquid byproduct in the heat exchanger vessel; l) returning the substantially dry ammonia vapor to the vapor region of the accumulator vessel; m) supplying the substantially dry ammonia vapor received in the vapor region of the accumulator vessel to the compressor so as to be subsequently converted to substantially non-aqueous liquid ammonia refrigerant; and n) repeating steps c through k.

These and other aspects of the present invention will be described in greater detail hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. **1** is a highly simplified transverse, vertical, sectional view with some surfaces removed of a prior art gravity flooded evaporator employed with a prior art ammonia refrigeration system.

FIG. **2** is a greatly simplified, transverse, vertical, sectional view of a prior art liquid overfeed evaporator arrangement employed with a prior art liquid ammonia refrigeration system.

FIG. **3** is a partial, greatly simplified illustration of an evaporator arrangement as used in a prior art direct expansion ammonia refrigeration system.

FIG. **4** is a longitudinal, vertical, sectional view taken through a prior art smooth inside diameter horizontal evaporator tube showing the refrigerant flow patterns exhibited by same.

FIGS. **4A-4E** are transverse, vertical, sectional views taken from various positions along lines **4A-4A**, **4B-4B**, **4C-4C**, **4D-4D**, and **4E-4E** as seen in FIG. **4**.

FIG. **5** shows four exemplary and non-limiting embodiments of wicking structures forming a feature of the present invention.

FIG. **5A** is a transverse, vertical, sectional view taken through one form of an evaporator tube finding usefulness in the present invention.

FIG. **5A1** is a longitudinal, vertical, sectional view taken from a position along lines **A1-A1** of FIG. **5A**.

FIG. **5A2** is a longitudinal, vertical, sectional view taken from a position along lines **A2-A2** of FIG. **5A**.

FIG. **5B** is a transverse, vertical, sectional view taken through another form of an evaporator tube finding usefulness in the present invention.

FIG. **5B1** is a longitudinal, vertical, sectional view taken from a position along lines B-B of FIG. **5B**.

FIG. **5B2** is a greatly exaggerated fanciful depiction of a portion of the structure as seen in FIG. **5B1** as indicated by the arrow.

FIG. **5C** is a transverse, vertical, sectional view of yet another form of an evaporator tube finding usefulness in the present invention.

FIG. **5C1** is a longitudinal, vertical, sectional view taken from a position along lines C-C of FIG. **5C**.

FIG. **6** is a graphical depiction showing the bubble point temperature of liquid ammonia refrigerant when combined with various concentrations of water.

FIG. **7** is a graphical depiction showing the increase in the bubble point temperature of ammonia versus ammonia vapor quality at a 3% water concentration as calculated at a temperature of saturation of –40 degrees F.

FIG. **8** is a graphical depiction showing the concentration of water remaining in liquid versus the ammonia vapor quality. This is calculated at a 3% concentration of water with ammonia at an initial temperature of saturation of –40 degrees F.

FIG. **9** is a graphical depiction showing ammonia liquid mass flow rate versus water concentration. This is calculated at a 3% water concentration with ammonia with an initial temperature of saturation at –40 degrees F.

FIG. **10** is a greatly simplified, schematic view of one form of the direct expansion ammonia refrigeration system of the present invention.

FIG. **11** is a greatly simplified, fragmentary, schematic view of a feature of the present invention.

FIG. **12** is a second form of the inventive feature as seen in FIG. **11**.

FIG. **13** is a greatly simplified schematic view depicting the evaporator refrigerant circulation pattern as provided with an evaporator having horizontal air flow of the present invention.

FIG. **14** shows a second form of an evaporator refrigerant circulation pattern for an evaporator having vertical air flow of the present invention.

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).

Referring more specifically to the drawings, the present invention provides a novel means, as will be discussed in greater detail hereinafter, for mitigating the poor evaporator performance which has been experienced in prior art direct expansion ammonia refrigeration systems which have been used heretofore. Without being confined to any particular theory, it is believed that poor evaporator performance appears to have been caused, at least in part, by stratified-wavy two phase flow patterns of refrigerant in the evaporator tubes as will be discussed hereinafter; and the continuous removal of water from an ammonia refrigerant which is used in a direct expansion ammonia refrigeration system as will be described and discussed in detail in FIGS. **5-14**, respectively. As discussed earlier in the background section of the present invention, it has long been known that even small amounts of water in solution with ammonia will significantly increase the boiling point of the liquid ammonia refrigerant employed in a direct expansion ammonia refrigeration system such that the prior art thermostatic expansion valves cannot correctly sense the correct superheat in the refrigerant vapor leaving the evaporator which has been employed with same. Please see FIGS. **6-9**. The result of a malfunctioning thermostatic expansion valve in prior art systems has resulted in a significant amount of water-rich refrigerant solution which increasingly collects in an evaporator employed with such prior art direct expansion ammonia refrigeration systems utilized, heretofore. This ammonia-water refrigerant mixture, as discussed, has had the effect of reducing the performance of such direct expansion ammonia evaporation systems (FIGS. **6-9**) and further, if supplied to a compressor used with such systems may ultimately result in a mechanical failure of the compressor, thus increasing the cost of operation of such refrigeration systems.

Referring now to FIG. **1**, a prior art gravity flooded evaporator **10** as employed in a prior art gravity flooded ammonia refrigeration system (not shown) is generally indicated by the numeral **11**. The evaporator **10** as seen in FIG. **1** includes a plurality of evaporator tubes having smooth inside walls, and which are generally indicated by the numeral **12**. The evaporator **10** is coupled in fluid flowing relation relative to a supply conduit **13**. The supply conduit **13** is coupled in fluid flowing relation relative to an intake or supply manifold **14** which, in turn, supplies liquid ammonia refrigerant **21** to the lowest point in the evaporator **10**. Still further, it will be seen that the prior art arrangement of FIG. **1** includes an exhaust manifold **15** which is coupled in downstream fluid flowing relation relative to each of the plurality of evaporator tubes **12**. The exhaust manifold **15** is coupled in fluid flowing relation to a return conduit **16**, and which is further coupled in fluid flowing relation relative to a surge drum/container **20**. The surge drum container contains a quantity of liquid ammonia refrigerant generally indicated by the numeral **21**. The liquid ammonia refrigerant **21** is supplied to the surge container **20** by means of a liquid refrigerant makeup conduit which is generally indicated by the numeral **22**. Still further, a suction conduit, which is generally indicated by the numeral **23**, is coupled in fluid flowing relation relative to the surge drum or container **20**. A compressor suction which is provided to same causes the liquid ammonia refrigerant **21** to move along the supply conduit **13**, and into the plurality of evaporator tubes **12**, where the liquid ammonia refrigerant then boils or otherwise evaporates therein as seen in FIG. **4** and which will be discussed in greater detail hereinafter. In the arrangement as seen in FIG. **1**, a liquid level switch **30** is provided and which is coupled by electrical conduits **31** to both the supply conduit **13**, as well as a given location on the surge drum/container **20** in order to detect the relative level of the liquid ammonia refrigerant **40**. Positioned in appropriate metering relation along the liquid refrigerant makeup conduit **22** is a hand-operated expansion valve **60** of conventional design. Still further, as seen in FIG. **1**, a liquid level solenoid valve **50** is provided, and which is positioned in selective fluid metering relation along the same conduit. The liquid level solenoid valve **50** is connected by means of an electrical conduit **51** to the liquid level switch **30**. The liquid level switch **30** is effective so as to control the liquid level solenoid valve **50**, and allow liquid ammonia refrigerant makeup to be delivered to the surge drum/container **20**. The hand-operated expansion valve **60** as shown is typically manually set to meter the approximate required amount of refrigerant to the evaporator. In the arrangement as seen in FIG. **1**, it should be noted that the level **40** of the ammonia refrigerant **22** is approximately 18 inches higher than the top of the evaporator **20**.

Referring now to FIG. **2**, a second, prior art, liquid overfeed ammonia refrigeration system is shown. The system, which is generally indicated by the numeral **71**, includes a plurality of evaporators **70** which are of similar construction to that seen with respect to FIG. **1**. In this regard, the plurality of evaporators **70** each include a plurality of evaporator tubes generally indicated by the numeral **72**, and which have smooth inside walls. The evaporator tubes are connected in fluid flowing relation relative to a supply conduit which is generally indicated by the numeral **73**. The supply conduit **73** is operable to supply liquid ammonia refrigerant, as described, below, to the respective evaporators. Again, each of the plurality of evaporators **70** includes an intake manifold **74** which is coupled to the respective supply conduits **73**, and which further supplies the liquid ammonia refrigerant to the respective evaporator tubes **72** where the liquid ammonia refrigerant evaporates or otherwise boils as will be described in greater detail below. Still further, each of the plurality of evaporators **70** is coupled in fluid flowing relation to an exhaust manifold **75**. The exhaust manifold **75** is, in turn, coupled in fluid flowing relation relative to a return conduit **76** which is also labeled "wet suction." As seen from FIG. **2**, a first hand-operated expansion valve **77** is provided and which selectively meters the liquid ammonia refrigerant, as described below, to each of the plurality of evaporators **70**. As illustrated in FIG. **2**, a plurality of refrigerant pumps **80** are mounted in fluid supplying relation relative to the supply conduit **73**. The respective plurality of pumps are coupled in fluid flowing relation relative to a liquid supply leg **81** of a low pressure receiving vessel **90**. The liquid supply leg is in gravity receiving relation relative to the low pressure receiving vessel **90**. The low pressure receiving vessel **90** contains a quantity of liquid ammonia refrigerant which is generally indicated by a liquid level **100**. In this arrangement, the liquid ammonia refrigerant, under the influence of gravity, moves through the liquid supply leg **81** and then enters the supply conduit **73** where it is pumped, under pressure, by the plurality of refrigerant pumps **80**, to the respective evaporators **70**. As can be seen, the low pressure receiving vessel **90** is coupled in fluid receiving relation relative to the return or wet suction conduit **76**. Still further, it will be seen that a compressor conduit **91** is coupled in fluid flowing relation to the low pressure receiving vessel **90**. A compressor (not shown) is operable to remove pressure from the low pressure receiving vessel **90**. Liquid ammonia refrigerant is supplied to the low pressure receiving vessel **90** by means of a liquid refrigerant makeup conduit which is generally indicated by the numeral **92**. Still further, the liquid ammonia refrigerant level **100** within the low pressure receiving vessel **90** is maintained by means of a liquid level control which is generally indicated by the numeral **110**. The liquid level control **110** is coupled to individual conduits **111**, and is operable, when appropriately controlled, to maintain the liquid ammonia refrigerant level **100** within a given range. As illustrated in FIG. **2**, a liquid level solenoid valve **112** is electrically coupled by means of an electrical conduit **113** to the liquid level control **110**. The liquid level solenoid valve is positioned in selective fluid metering relation therealong the liquid refrigerant makeup conduit **92**. Still further, a second hand-operated expansion valve **114** is positioned in metering relation therealong the liquid refrigerant makeup conduit **92**. Again, it should be understood that the individual hand-operated expansion valves **77** and **114**, respectively, are manually set to meter the approximate required amount of refrigerant required by the evaporators **70**. It will be appreciated that the vacuum produced by the compressor suction on the low pressure receiving vessel **90** is operable to draw ammonia refrigerant exiting the respective evaporators **70** back to the low pressure receiving vessel **90**.

Referring now to FIG. **3**, a portion of a prior art direct expansion ammonia refrigeration system is generally indicated by the numeral **140**, therein. As seen in that drawing, the portion of the system **140** includes an evaporator which is generally indicated by the numeral **150**. The evaporator comprises a plurality of evaporator tubes **151**. Each of the plurality of evaporator tubes **151** have an intake end **152** and an opposite exhaust end which is generally indicated by the numeral **153**. The evaporator tubes all have a smooth interior facing surface. The exhaust ends **153** are each coupled in fluid flowing relation relative to an exhaust manifold which is generally indicated by the numeral **154**. The exhaust manifold **154** experiences a vacuum or suction as provided by a compressor (not shown) as indicated in the drawing. As seen in FIG. **3**, a temperature sensor which is generally indicated by the numeral **155** is located in close proximity to the exhaust manifold **154**. Still further, as seen in FIG. **2**, a liquid refrigerant supply line **156** is coupled in fluid flowing relation relative to the intake ends **152** of the respective plurality of evaporators **151**. As seen in FIG. **3**, a thermostatically controlled expansion valve which is generally indicated by the numeral **160** is positioned in selective fluid metering relation therealong the liquid refrigerant supply line **156**. Still further, and positioned downstream relative to the thermostatically controlled expansion valve **160** is a distributor **170** of conventional design. The distributor **170** couples a source of liquid ammonia refrigerant which is traveling along the liquid refrigerant supply line **156** with the intake ends **152** of the plurality of evaporator tubes **151** by means of a plurality of supply leads which are generally indicated by the numeral **171**. A liquid level solenoid valve which is generally indicated by the numeral **172** is positioned upstream relative to the thermostatically controlled expansion valve **160** and meters liquid ammonia refrigerant to the thermostatically controlled expansion valve **160**. Still further, as seen in FIG. **3**, a pressure equalizer conduit **173** extends between a position which is slightly downstream relative to the exhaust manifold **154** and into fluid flowing contact relative to the thermostatically controlled expansion valve **160**. Still further, a temperature control capillary tube **174** extends therebetween the temperature sensor **155** and the thermostatically controlled expansion valve **160** in order to facilitate the control of same.

The arrangement as seen in FIG. **3** illustrates a prior art direct or "dry" expansion evaporator **150** which is automatically fed with liquid refrigerant by a thermostatically controlled expansion valve **160**. It should be understood that the expanded refrigerant leaving the thermostatically controlled expansion valve **160** is equally distributed to multiple parallel circuits herein indicated by the numerals **151** by the refrigerant distributor **170**. The thermostatically controlled expansion valve **160** continuously measures either mechanically, or electronically, the amount of superheat in the refrigerant vapor leaving the evaporator at the point indicated by **190** by means of a temperature sensor **155**, and pressure sensor which is generally indicated by the numeral **210**. As should be understood, the word "superheat" for the purposes of this application means a sensible heat in a gas above the amount needed to maintain the gas phase thereof. As the thermostatically controlled expansion valve **160** senses increasing superheat, it opens thereby allowing more liquid ammonia refrigerant (not shown) to enter the evaporator **150**. On the other hand, as the thermostatically controlled expansion valve **160** senses decreasing superheat, it closes thereby decreasing the amount of refrigerant entering the evaporator **150**. As should be understood, the liquid line solenoid valve **172** is normally open during operation. However, when the cooling load in a refrigerated space (not shown) is satisfied, or when a defrost cycle is initiated, the liquid level solenoid valve **172** is closed thereby shutting off the flow of liquid ammonia refrigerant to the evaporator **150**. This direct expansion method of controlling the flow of liquid refrigerant to the evaporator **150** is simpler, less costly and minimizes the amount of liquid or refrigerant in the system as compared to the prior art gravity flooded and liquid overfeed systems as shown in FIGS. **1** and **2**, respectively.

Referring now to FIG. **4**, a multiplicity of two-phase flow patterns during evaporation of the liquid ammonia refrigerant in smooth inside diameter horizontally disposed evaporator tubes **12**, is shown. When viewing FIG. **4**, it should be understood that the flow of liquid ammonia refrigerant is from the left side of the drawing to the right side of the drawing. The flow includes a single phase liquid region **270**; bubble flow region **260**; plug flow region **250**; wavy flow region **240**; annular flow region **230**; and dry wall flow region **220**. Not every region may be present at any one time depending on the design. As seen in this drawing, and with smooth, inside diameter evaporator tubes **12**, the highly desirable annular flow pattern is generally indicated by the numerals **220** and **230** respectively and which are seen in FIGS. **4D** and **4E**, respectively. The flow pattern is created by vapor shear forces. Still further, the highly undesirable stratified-wavy flow patterns, as seen in FIG. **4C**, and which is indicated by the numeral **240**, unavoidably appear with low temperature direct expansion ammonia evaporator designs of the prior art. In this regard, a direct expansion ammonia refrigeration system operating at low temperatures operates predominately in this stratified, wavy flow region. The stratified-wavy flow patterns **240** as seen in FIG. **4C**, appears to severely restrict the performance and the effective use of prior art direct expansion ammonia refrigeration systems as described earlier. The stratified-wavy flow pattern **240** appears to effect the boiling heat transfer coefficients of the liquid ammonia refrigerant and therefore evaporator performance is severely inhibited by stratified-wavy flow patterns **240**.

Referring now to FIG. **5**, various wicking structures which constitute a feature of the present invention are shown. As illustrated, one aspect of the present invention relates to a plurality of evaporator tubes **200** which are incorporated within an evaporator structure that is generally indicated by the numeral **390** in FIG. **10** and following. The plurality of evaporator tubes have an outside facing surface **201**, and an opposite inside facing surface **202**, respectively. The inside facing surface defines a cavity **203** which allows a source of liquid ammonia refrigerant to pass therethrough. Referring now to FIGS. **5A** and **5A1**, in a first form of the present invention which includes various wicking structures, an evaporator tube **200** is provided and which is coupled in fluid receiving relation relative to a source of liquid ammonia refrigerant (not shown), and which has an inside facing surface **202** having a wicking structure generally indicated by the numeral **206**. In this arrangement, by capillary action facilitated by the wicking structure **206**, the liquid ammonia refrigerant is drawn up onto and along the inside facing surface **201** of the evaporator **200** so as to substantially mitigate the negative effect of any stratified and/or wavy flow patterns **240** of the liquid ammonia refrigerant within the evaporator tube **200**. The wicking structure **206**, as seen in this form of the invention, comprises a multiplicity of helical grooves having a depth of about 0.005 to about 0.05 inches, a spacing of about 0.01 to about 0.10 inches; and a lead angle of about 15 degrees to about 90 degrees, respectively. Referring now to FIG. **5A2**, a second form of the wicking structure **207** is shown. The evaporator tube **200** in this form includes a wicking structure **205** which is formed into the inside facing surface **201**, and which comprises a multiplicity of cross-hatched knurls **207** which are formed into the inside facing surface of the evaporator tube **200**, and which are dimensioned so as to generate the desired capillary action. In the arrangement as seen in FIG. **5A2**, the respective cross-hatched knurls **207** have a length of about 0.005 to about 0.05 inches; a spacing of about 0.01 to about 0.10 inches; and a lead angle of about 15 degrees to about 90 degrees, respectively.

Referring now to FIGS. **5B**, **5B1** and **5B2**, a third form of the wicking structure **205** comprising a feature of the present invention is shown. In this form of the invention, the direct expansion ammonia refrigeration system has a plurality of evaporator tubes **200** which have a wicking structure **208** which comprises a sintered metal coating which is deposited upon the inside facing surface **202** of the evaporator tube **200**. This sintered metal coating **208** is effective in drawing the liquid ammonia refrigerant, by capillary action, up onto the inside facing surface **202** of the evaporator tube **200**. In the arrangement as seen in FIGS. **5B**, **5B1** and **5B2**, the sintered metal coating is formed from a metal selected form the group comprising stainless steel; nickel; copper; and/or aluminum. Still further, in this arrangement (FIG. **5B2**), the sintered metal coating **208** is formed to have a plurality of pores **204** having a pore radius of about 0.001 to about 0.04 centimeters. In yet another form of the wicking structure **205** of the present invention and as seen by reference to FIGS. **5C** and **5C1**, the wicking structure **205** comprises a wire mesh which is generally indicated by the numeral **209**, and which has a mesh size ranging from about 60 to about 450 openings per inch. Again, the wire mesh **280** is formed from a metal selected form the group comprising stainless steel; nickel; copper; and/or aluminum. All forms of the invention as seen in FIG. **5** produce effective capillary action so as to facilitate the advantageous operation of the present invention.

FIG. **6** illustrates, in a graph, the effects of water on the boiling point of a source of liquid ammonia refrigerant **290** when measured at 10.398 psia and a temperature of −40 degrees F. As will be seen from reviewing that graphical depiction, as the concentration of water and liquid ammonia refrigerant increases, so does the boiling or "bubble" point of the ammonia-water solution. Whenever water is present in the liquid ammonia refrigerant, even in small amounts, the boiling point increases and performance of any direct expansion evaporator will be substantially impeded. In addition, in any prior art arrangement such as seen in FIGS. **1-3**, the thermostatically controlled expansion valve utilized with same will typically allow aqueous ammonia to exit the evaporator due to its failure to detect the correct superheat of the refrigerant vapor exiting same. As earlier discussed, and as seen in FIGS. **6-9**, the introduction of even a small amount of water to a direct expansion ammonia refrigeration system is quite disadvantageous because such aqueous ammonia will usually damage any compressor utilized with the refrigeration system.

Referring now to FIG. **7**, this drawing illustrates the relationship between the increase in boiling or "bubble" point **300** of a liquid ammonia refrigerant as it enters an evaporator circuit at a location which is positioned at the left of the X axis **310** and evaporates over the length of the evaporator circuit moving in a direction from left to right **320** where it exits the evaporator at a point **330** as seen on the graph. Again, this shows the impact of a small amount of water in a refrigeration system.

FIG. **8** graphically depicts the corresponding increase in the concentration of water in the liquid ammonia refrigerant **340** as the liquid ammonia refrigerant enters the evaporator circuit at the left **350** of the X axis and evaporates over the length of the evaporator circuit moving from the left **350** to the right **360** to exit the evaporator at a point indicated by the numeral **370**.

FIG. **9** illustrates in a graphical depiction the mass flow rate of a liquid refrigerant mixture comprising ammonia and water **380** leaving the output of an evaporator versus the concentration of water in the liquid mixture leaving the evaporator. Again, it is seen that even a small amount of water will seriously impair the performance of a refrigeration system.

Referring now to FIG. **10** and following, one form of practicing the present invention is seen. In this regard, the direct expansion ammonia refrigeration system **385** includes a plurality of evaporators **390** each incorporating at least some of the evaporator tubes **200** which were described earlier and seen in FIG. **5**. The evaporators **390** are each coupled in fluid flowing relation relative to a distributor **310**. The distributor **310** further mounts a plurality of fluid leads which are generally indicated by the numeral **311**, and which delivers a source of liquid ammonia refrigerant **539** to the respective evaporators **390**. Still further, and as described earlier, the respective evaporators **390** include an exhaust manifold **312**. It should be understood that the plurality of evaporator tubes **200** are coupled in fluid flowing relation relative thereto. Still further, and mounted near the exhaust manifold **312** is a temperature sensor **313** which is coupled by electrical leads **314** to a thermostatic expansion valve **400** which is positioned upstream relative to the distributor **310**. As a general matter, the direct expansion evaporators **390**, as seen in FIG. **10**, receive liquid ammonia refrigerant by means of the thermostatic expansion valves **400**. Further, the liquid ammonia refrigerant boiled in the evaporators **390** is returned through the suction return line or conduit **410** to a combined suction accumulator vessel and concentrator heat exchanger which is generally indicated by the structure which is contained within the box labeled **420**, and which is described and shown in one form in FIG. **11**. In the arrangement as found in FIG. **10** and following, it should be appreciated that high pressure and temperature refrigerant gas from the discharge of the compressor **490** first flows to a high efficiency oil separator which generally indicated by the numeral **492**, and which is well known in the art. In the arrangement as seen in FIG. **10** and following, it is important to understand that oil must be removed from the source of the liquid ammonia refrigerant by the high efficiency oil separator **492** so as to prevent any oil from reaching the respective evaporators **390**. If oil was to reach these evaporators, the oil would have the effect of quickly fouling the wicking structures **205** as seen in FIG. **5**, and which are located on the inside facing surfaces **202** of the respective evaporator tubes **200**. The fouling of the wicking structures **205** in the evaporator tubes **200** would have the effect of reducing the capillary action needed to draw the source of a liquid ammonia refrigerant **539** up onto the evaporator tube walls. This would, in turn, reduce the evaporator **390** performance by allowing the stratified wavy flow pattern of the refrigerant within the respective evaporator tubes **200**.

The source of gaseous ammonia refrigerant **539** flows from the oil separator **492** by way of the conduit **493** to the condenser **650** where it is condensed to liquid form **539** and passes by way of conduit **651** into a high pressure receiver or vessel **540**. Positioned downstream in fluid flowing relation relative to the high pressure receiver **540** by means of a conduit **541** is a direct expansion mechanical subcooler which is generally graphically indicated by the numeral **530** in FIG. **10**. The direct expansion mechanical subcooler **530**, which is well known in the art, is sized as to provide enough subcooling of the source of a liquid ammonia refrigerant **539** leaving the high pressure receiver **540** so as to prevent flashing or rapid evaporation of the liquid refrigerant in the liquid delivery lines **550** due to frictional and static pressure drops. A liquid delivery line pressure regulating valve which is generally indicated by the numeral **560** is located in fluid metering relation along the liquid delivery line **550**. This valve is operable to maintain the liquid delivery line pressure lower than the defrost hot gas pressure which is determined by the defrost pressure regulating valve **570**. This pressure differential allows the source of a liquid ammonia refrigerant **539** condensed in the evaporators **390** during a defrost to be pushed back into the liquid delivery lines **550** and then used by other non-defrosting evaporators **390**.

As should be understood, during a defrost cycle of the refrigeration system **385**, the flow of liquid ammonia refrigerant **539** is first shut off to the designated defrosting evaporators **390** by first shutting the liquid level solenoid valve which is generally indicated by the numeral **610**. A suction stop valve **620** is provided and remains open to allow liquid refrigerant in the evaporator to completely evaporate or be pumped out. Once this pump out period is completed, the suction stop valves **620** are closed. It is important to note that in large systems with multiple evaporators **390** approximately one-third of the evaporators in the system **385** are defrosted while the remaining two-thirds continue operating normally. In the arrangement as shown in FIG. **10** hot ammonia gas from the discharge of the compressor **490** is then admitted to the defrosting evaporator coil **390** through a hot gas solenoid valve which is generally indicated by the numeral **580**. The hot gas first warms an evaporator drain pan loop which is generally indicated by the numeral **590**, and which is located in a drain pan (not shown) which is located under the defrosting evaporator core **390**. The hot gas then passes through a check valve **600**, and on into the evaporator **390** by means of the distributor **311**, where it subsequently condenses to liquid form. When the hot ammonia gas condenses to liquid form, this refrigerant warms the evaporator **390** surface in the process and melts accumulated frost and ice. Condensed liquid ammonia refrigerant from the defrosting then passes through a liquid drainer **630** of conventional design, and a check valve **640**. The liquid refrigerant is then fed back into the liquid delivery line **550** where it is used by other non-defrosting evaporators **390**.

Referring now to FIG. **11**, one form of a combined accumulator vessel and concentrator heat exchanger vessel **420** (FIG. **10**) is shown in a greatly enhance view. The structure **420** includes a low pressure accumulator vessel **660**; concentrator heat exchanger vessel **662**; and liquid transfer vessel **664**. These vessels are each fluidly coupled together and designed to work together to manage and therefore eliminate any ammonia-water liquid which leaves the respective evaporators **390**. As earlier discussed, liquid ammonia refrigerant has a strong affinity for water and consequently the management of any ammonia-water liquid leaving the evaporators **390** is important inasmuch as this same solution may, if left unchecked, have the effect of damaging the compressor **490** should it be received in same, as well as reduce the overall performance of the refrigeration system **385**. In this regard, the source of liquid ammonia refrigerant **539** which is boiled in the respective evaporators **390** is returned through the suction return line **670** to a special low-pressure accumulator vessel which is generally indicated by the numeral **660**. Any ammonia-water liquid mixture (hereinafter referred to as aqueous ammonia refrigerant) **680** leaving the evaporators **390** is captured by the accumulator vessel **660** and is prevented from reaching the compressor **490**. It is important to understand that only substantially dry ammonia vapor **657** returns to the compressor **490** from the top portion or vapor region **661** of the accumulator vessel **660** where it is safely recompressed. The substantially dry ammonia vapor **657** is delivered to the compressor by means of conduit **656**.

The liquid transfer vessel **664** which is coupled in fluid flowing relation relative to the low pressure accumulator vessel **660** acts in a fashion so as to maintain a safe liquid refrigerant level in the low pressure accumulator vessel **660**. In this regard, any accumulating aqueous ammonia refrigerant **680** which reaches the level of the inlet connection indicated by the numeral **690** drains by gravity through a low spring pressure check valve which is generally indicated by the numeral **700** and into the liquid transfer vessel **664**. A multifunction controller **702** is provided, and is electrically coupled with the various assemblies described, and which further controls a low pressure solenoid vent valve **704**; a high pressure solenoid vent valve **706**; a liquid level switch **708**; and a low head pressure liquid transfer pump **710**. During the filling cycle, the multifunction controller **702** keeps the low pressure solenoid vent valve **704** open and fluidly coupled to the vapor region **661** of the low pressure accumulator vessel **660**. Still further, the high pressure solenoid vent valve **706** is closed to the top of the high pressure receiver tank **540**; and the low head pressure liquid transfer pump **710** is de-energized. When the liquid ammonia level **712** of the liquid transfer vessel **664** reaches the level of the liquid level switch **708**, the multifunction controller **702** is operable to close the low pressure vent solenoid valve **704**; open the high pressure vent solenoid valve **706**; and energize the low head pressure liquid transfer pump **710**. By this action, the low head pressure liquid transfer pump **710** pumps the liquid aqueous ammonia refrigerant in the liquid transfer vessel **664** through a check valve **714** to the high pressure receiver **540** by means of a conduit **715**. This aqueous ammonia refrigerant is then mixed with condensed ammonia refrigerant **748** received from the condenser **650**. The multifunction controller **702** keeps the low head liquid transfer pump **710** energized for a predetermined period of time which is sufficient so as to substantially empty the liquid transfer vessel **664** of its liquid mixture. After this predetermined time period expires, the multifunction controller **702** de-energizes the low head liquid transfer pump **710**; closes the high pressure vent solenoid valve **706**; and opens the low pressure vent solenoid valve **704** to resume the filling cycle.

Referring still to FIG. **11**, it should be understood that the aqueous ammonia refrigerant **680** enters the concentrator heat exchanger vessel designated **662** by gravity and by means of an inlet connecting pipe or first conduit which is generally indicated by the numeral **663**. In the arrangement as seen, it is important to note that the inlet connecting pipe has a pipe entrance or first end **716** which is at an elevation lower than the concentrator heat exchanger vessel **662**. Still further, the pipe outlet or second end **718** is at an elevation higher than the concentrator heat exchanger vessel **662**. This arrangement of the inlet connecting pipe **663** prevents an aqueous ammonia refrigerant mixture **680** from flowing back into the low pressure suction accumulator vessel **660** as it is heated by the concentrator heat exchanger vessel **662**. Aqueous ammonia refrigerant enters into the concentrator heat exchanger vessel **662** where it is warmed and distilled by a heating element **690**. With increasing temperature, the aqueous ammonia refrigerant is increasingly vaporized in the concentrator heat exchanger vessel **662** to produce substantially dry ammonia, gas **657**. This gas **657** returns by means of the conduit **747** to the top vapor region **661** of the low pressure accumulator vessel **660**. Again, a multifunction controller **720** senses the liquid. level **722** in the concentrator heat exchanger vessel **662** by means of a liquid level sensor **724**, and the temperature of the liquid mixture **726** by way of a temperature sensor **728**. Still further, the controller **720** controls a drain solenoid valve which is generally indicated by the numeral **730**, and which is positioned downstream of the concentrator heat exchanger vessel **662**. The temperature sensor as provided at **728**, and the drain opening **734** are located at the end of the concentrator heat exchanger vessel **662** which is opposite to the inlet opening which is generally indicated by the numeral **736**. When the multifunction controller **720** senses that an acceptably concentrated aqueous ammonia byproduct solution **733** is present to the level of the liquid level switch **724** and the temperature of the solution **730** is at or above 95 degrees F., the controller then opens the normally closed drain solenoid valve **730** and energizes the liquid purge pump **732** for a predetermined period of time. The multifunction controller **720** keeps the drain solenoid valve **730** and liquid purge pump **732** energized long enough to empty the concentrator heat exchanger vessel **662** of its acceptably concentrated aqueous ammonia byproduct solution **733**. For purposes of this application, an acceptably concentrated aqueous ammonia byproduct solution has an ammonia concentration of less than about 20% by weight, or otherwise is in a concentration which provides no significant environmental impact if the aqueous ammonia solution is discharged to the immediate environment. After this predetermined period of time expires, the multifunction controller **720** deenergizes the liquid purge pump **732** and closes the drain solenoid valve **730** to resume filling the concentrator heat exchanger vessel **662** with aqueous ammonia refrigerant.

As seen in FIG. **11**, a high liquid level alarm switch **744** is operably coupled with the low pressure suction accumulator vessel **660**. This switch is operable, in combination with the controller **720**, to shut down the refrigeration system **385** in the event that the safe maximum liquid level **746** is exceeded. In addition to the foregoing, and as seen in FIG. **11**, an oil drain valve **742** is coupled in fluid flowing downstream relation relative to the liquid leg **750** of the low pressure suction accumulator vessel **660**. The oil drain valve **742** allows excess oil to be removed from the system periodically by means of an oil pot of conventional design (not shown).

Referring now to FIG. **12**, this view illustrates an alternative version of one feature of the present invention. In this regard, a special low pressure accumulator vessel which is generally indicated by the numeral **660**; concentrator heat exchanger vessel generally indicated by the numeral **662**; and high head pressure liquid transfer pump **758** are coupled in fluid flowing relation together, and are arranged so as to manage the aqueous ammonia refrigerant **680** leaving the respective evaporators **390**. The refrigerant which has boiled in the evaporators **390** is returned through the suction return line **660** to the special suction accumulator vessel **660** as seen in FIG. **12**. Any aqueous ammonia refrigerant **680** leaving the evaporators **390** is captured by the accumulator vessel **660**, and prevented from reaching the compressor **490**. In the arrangement as seen in this drawing, only substantially dry ammonia vapor **657** returns to the compressor **490** from the top or vapor region **661** of the accumulator vessel **660** where it is safely recompressed. In the arrangement as seen in FIG. **12**, the high head liquid transfer pump **758** acts to transfer the liquid aqueous ammonia refrigerant **680** which is received from the respective evaporators **390** to the high pressure receiver **540**. A multifunction controller **756** is provided and which energizes the high head liquid transfer pump **758** whenever the aqueous ammonia refrigerant is above the low liquid level switch **752** as seen in that drawing. When it is energized, the high head liquid transfer pump **758** pumps aqueous ammonia refrigerant from the bottom of the liquid leg **750** through a check valve **754** to the high pressure receiver **540**. Again, as in FIG. **11**, aqueous ammonia refrigerant **680** enters the concentrator heat exchanger vessel **662** by gravity through an inlet connecting pipe **663** where it is warmed and distilled by the heating element **690**. The heat energy causes the liquid ammonia refrigerant to vaporize into substantially dry ammonia vapor or gas **657**. Any vaporizing refrigerant in the concentrator heat exchanger vessel **662** returns to the top or vapor regions **661** of the low pressure accumulator vessel **660** through a conduit generally indicated by the numeral **747**. The heating element **690**, as seen in FIGS. **11** and **12**, are temperature self-regulating so that the temperature of the element cannot exceed 125 degrees F. The heating element **690** may be an electric resistance heater or heat exchanger utilizing a heated fluid such as glycol or a warm refrigerant liquid. In this regard, it is important to understand that the conduit entrance **716** to the inlet connecting pipe **663** is at an elevation lower than the concentrator heat exchanger vessel **662**. Still further, it is important to note that the pipe outlet **718** is at an elevation higher than the concentrator heat exchanger vessel **662**. This arrangement of the inlet connecting conduit **663** prevents the water-ammonia liquid or solution **680** from flowing back into the low pressure accumulator vessel **660** as it is heated and its density increases due to the increasing concentration of water in the mixture. Again, a multifunction controller **720** senses the liquid level **722** in the concentrator heat exchanger vessel **662** by way of a liquid level sensor **724**. The temperature of the liquid mixture **726** is taken by way of a temperature sensor **728**. The temperature sensor and the liquid level sensor controls a drain solenoid valve **730** and a liquid purge pump **732**. The temperature sensor **728** and the drain opening **734** are located at the end of the concentrator heat exchanger vessel **662** which is opposite the inlet opening **736**. When the multifunction controller **720** senses that acceptably concentrated aqueous ammonia byproduct **783** is present to the level of the liquid level switch **724**, and the temperature of the same acceptably concentrated aqueous ammonia byproduct is at or above 95 degrees F. it opens the normally closed drain solenoid valve **730** and energizes the liquid purge pump **732** for a preset period of time. The multifunction controller **720** keeps the drain solenoid valve **730** and the liquid purge pump energized long enough to empty the concentrator heat exchanger vessel **662** of its byproduct solution **233**. During this draining cycle, the liquid purge pump **732** pumps the byproduct mixture **733** through a check valve **738** to a drain **740**. After the preset period of time expires, the multifunction controller **720** deenergizes the liquid purge pump, closes the drain solenoid valve **730** to resume filling the concentrator heat exchanger vessel **662** with aqueous ammonia refrigerant **680**. Again, this draining does not take place unless the ammonia byproduct **733** concentration is less than about 20% by weight of ammonia. In the arrangement as seen in the drawings, a high liquid level alarm switch **744** senses the liquid level in the low pressure accumulator vessel **660** and shuts down the refrigeration system **385** in the event that the safe maximum liquid level **746** is exceeded. An oil drain valve **742** is installed at the bottom of the cumulative liquid leg **750** to allow excess oil to be removed from the system periodically by way of an oil pot of conventional design (not shown).

FIGS. **13** and **14** illustrate properly designed direct expansion ammonia evaporator **390** fluid circulating arrangements. For evaporators **390** which are oriented for operation with vertical air flow **770**, liquid ammonia refrigerant **539** enters through the refrigerant distributor **780** at the highest point in the evaporator **770**. The refrigerant passes through multiple parallel fluid flowing circulating circuits such that each circuit is freely draining by gravity to the next adjoining level, that is, each successive pass in the refrigeration circuit is at the same or lower elevation. Refrigerant vapor exits the evaporator **770** at the lowest point indicated by the numeral **790**. Again, an air movement assembly here, generally indicated by the numeral **771** is provided and which; when energized, produces air movement through the evaporator **771**. For evaporators **800** which are oriented for horizontal air flow, the liquid refrigerant **539** enters through the refrigerant distributor **780** and again is provided at the highest point of the evaporator **800**. Similar to the vertical air flow evaporator, the refrigerant passes through the multiple parallel fluid flowing circuits such that each circuit is freely gravitationally drained, that is, each successive pass in the circuit is at the same or lower elevation. Refrigerant vapor exits the evaporator at the lowest point which is indicated by the numeral **790**.

Having described, more broadly the present invention, the specific inventive features of the present invention are now set forth. In its broadest aspect, the present invention relates to a direct expansion ammonia refrigeration system generally indicated by the numeral **385** in FIG. **10**. As seen therein, the direct expansion ammonia refrigeration system **385** includes a source of liquid ammonia refrigerant which is generally indicated by the numeral **539**; and at least one evaporator tube **200** coupled in fluid receiving relation relative to the source of liquid ammonia refrigerant **539**, and which has an inside facing surface **202** (FIG. **5**) having a wicking structure **205**. By capillary action, facilitated by the wicking structure **205**, the wicking structure is operable to effectively draw the liquid ammonia refrigerant **539** along the inside facing surface **202** of the evaporator tube **200** so as to substantially reduce any stratified and/or wavy flow patterns **240** of the liquid ammonia refrigerant **539** within the evaporator tube **200**. As seen in FIG. **5** and following, the wicking structure **205** may take on different forms including a multiplicity of helical grooves **206** which are formed into the inside facing surface **202** of the evaporator tube **200**, and which are dimensioned so as to generate the desired capillary action. In this regard, the helical grooves have a depth of about 0.005 to about 0.05 inches, a spacing of about 0.01 to about 0.10 inches; and a lead angle of about 15 degrees to about 90 degrees. In one possible form of the wicking structure **205**, as seen in FIG. **5**, the wicking structure comprises a multiplicity of cross-hatched knurls **207** formed into the inside facing surface **202** of the evaporator tube **200**, and which are dimensioned so as to generate the desired capillary action. In this regard, the cross-hatched knurls have a length of about 0.005 to about 0.05 inches; a spacing of about 0.01 to about 0.10 inches; and lead angle of about 15 degrees to about 90 degrees. In another possible form of the invention as seen in FIG. **5**, the wicking structure **205** comprises a sintered metal coating **208** deposited upon the inside facing surface **202** of the evaporator tube **200**, and which is effective in drawing the liquid ammonia refrigerant **539** by the effect of capillary action up onto the inside facing surface **202** of the evaporator tube **200**. With respect to the sintered metal coating **208**, this particular metal coating is formed from a metal selected from the group comprising stainless steel; nickel; copper; and/or aluminum. Further, the sintered metal coating **208** is formed to be porous and have a pore radius **204** of about 0.001 to about 0.04 centimeters. In yet another form of the wicking structure **205** as seen in FIG. **5**, the wicking structure comprises a wire mesh **209** which is telescopingly received within and substantially juxtaposed against the inside facing surface **202** of the evaporator tube **200**. The wire mesh **209** is formed from a metal selected form the group comprising stainless steel; nickel; copper; and/or aluminum. Still further, the wire mesh has a mesh size **210** ranging from about 60 to about 450 openings per square inch.

Another aspect or feature of the present invention relates to a direct expansion ammonia refrigeration system **385** which includes a source of liquid ammonia refrigerant **539**; and a direct expansion ammonia evaporator **390** as seen in FIG. **10**. A compressor **490** is provided, and which is coupled in fluid flowing relation relative to the source of liquid ammonia refrigerant **539**, and which provides the liquid ammonia refrigerant to the direct expansion ammonia evaporator **390**. Still further, an accumulator vessel **660** is provided, and which defines an internal cavity **659** having a liquid region **658**, and a vapor region **661**. The vapor region **661** is coupled in fluid receiving relation relative to the direct expansion ammonia evaporator **390**, and in fluid delivering relation relative to the compressor **490**. The liquid region **658** contains aqueous liquid ammonia **680** which is produced by, and received from, the respective evaporators **390**. Still further, a heat exchanger vessel **662** is provided, and which is coupled in fluid receiving relation relative to the liquid region **658** of the accumulator vessel **660**, and is further in fluid delivering relation relative to the vapor region **661** of the accumulator vessel **660**. The heat exchanger vessel **662** includes a heating element **690** which vaporizes the aqueous liquid ammonia **680** so as to deliver substantially dry ammonia vapor **657** to the vapor region **661** of the accumulator vessel **660**. The substantially dry ammonia vapor **657** is subsequently delivered to the compressor **490**. In addition to the foregoing, the heat exchanger vessel **662** further comprises a drain conduit **731** which removes any acceptably concentrated aqueous ammonia byproduct solution **733** remaining in the heat exchanger vessel **662** after the heating element **690** vaporizes a preponderance of the ammonia from the aqueous liquid ammonia solution **680**. For purposes of this application, an acceptably concentrated aqueous ammonia solution has an ammonia concentration of less than about 20% and can therefore be drained from the system and disposed of readily.

In addition to the foregoing features, the direct expansion ammonia refrigeration system **385** as described includes a drain solenoid valve **730** which is positioned along the drain conduit **731** and positioned in selective fluid metering relation relative to the heat exchanger vessel **662**. Still further, a temperature sensor **728** is mounted on the heat exchanger vessel **662**, and which senses the temperature of the aqueous liquid ammonia **680** which is contained therein. Additionally, a first liquid level sensor **724** for sensing the amount of the aqueous liquid ammonia **680** within the heat exchanger vessel **662** is provided. Additionally, a controller **720** is coupled with the temperature sensor **728** and the first liquid level sensor **724**. The controller **720** controls the level and amount of aqueous liquid ammonia **680** within the heat exchanger vessel **662**, and which further is electrically controllably coupled to the drain solenoid valve **730**. In the arrangement as seen in FIG. **10**, the heating element **690** of the heat exchanger vessel may comprise an electric resistance heater. In an alternative form, the heating element **690** of the heat exchanger vessel **662** may comprise a warm liquid heat exchanger.

In addition to the features noted above, the direct expansion ammonia refrigeration system **385** includes a first liquid conduit **663** which has a first end **716**, and a second end **718**. The first end **716** is coupled in fluid flowing relation relative to the liquid region **658** of the accumulator vessel **660**, and the second end **718** is coupled in fluid flowing relation relative to the heat exchanger vessel **662**. The first end **716** is positioned at an elevation below the heat exchanger vessel **662**, and the second end **718** is positioned at an elevation above the heat exchanger vessel **662**. In the arrangement as seen in the drawings (FIGS. **10** and **11**), the liquid region **658** and vapor regions **661** of the accumulator vessel **660** are defined relative to each other by a liquid level. In this regard, the accumulator vessel **660** has a minimum liquid level **666**, and a maximum liquid level **746**. As earlier described, the direct expansion ammonia refrigeration system **385** comprises a plurality of evaporation tubes **200** coupled with the source of liquid ammonia refrigerant **539**. Again, each evaporator tube **200** has an inside facing surface **202**, and at least some of the inside facing surfaces **202** have a wicking structure **205**, which is operable, by capillary action, to facilitate the drawing of the liquid ammonia refrigerant **539** along the inside facing surface **202** of the evaporator tubes **200** to achieve the benefits of the present invention. As seen in FIGS. **13** and **14**, the respective plurality of evaporator tubes **200** are coupled in sequential, fluid flowing relation together. More specifically, the evaporator tubes **200** are individually oriented in sequential gravity feeding relation one relative to the others, and wherein the source of ammonia refrigerant **539** enters the evaporator tubes **200** at the highest point, and exits the evaporation tubes at the lowest point. In addition to the foregoing, the direct expansion ammonia refrigeration system **385** further includes a liquid transfer vessel **664** for regulating the liquid level of the accumulator vessel **660**. Additionally, a second fluid conduit **681** is provided and which has a first end **682** which is coupled in fluid flowing relation relative to the accumulator vessel **660**, and a second end **683** which is coupled in fluid flowing relation relative to the liquid transfer vessel **664**. The first end **682** is positioned above the minimum liquid level **666** of the accumulator vessel **660**, and below the maximum liquid level **746** of the accumulator vessel **660**.

In addition to the foregoing features, a high pressure receiver vessel **540** is provided and which is coupled in selective, fluid flowing relation relative to the liquid transfer vessel **664** referred to in the paragraph, above. Additionally, a plurality of solenoid valves **704** and **706** are individually positioned in selective fluid metering relation therebetween the accumulator vessel **660** and the liquid transfer vessel **664**, and between the liquid transfer vessel **664**, and the high pressure receiver vessel **540**. Additionally, a controller **702** is provided for controlling the operation of the plurality of solenoid valves **704** and **706** so as to selectively regulate the liquid level **666** and **746** of the accumulator vessel **660**. Moreover, and as seen in FIG. **10**, a second liquid level sensor **744** is mounted on the accumulator vessel **660**, and which provides a signal relative to the accumulator vessel liquid level. The controller **702** receives the signal generated from the second liquid level sensor, and thereafter controllably operates a liquid transfer pump **710** which is coupled in selectively fluid removing relation relative to the liquid region **658** of the accumulator vessel **660**. Additionally, the high pressure receiver vessel **540** is coupled in fluid receiving relation relative to the liquid transfer pump **710**. The controller **702** operates the liquid transfer pump **710** to selectively transfer aqueous liquid ammonia **680** between the accumulator vessel **660**, and the high pressure receiver vessel **540**, based, at least in part, upon the signal generated from the second liquid level sensor **744**, so as to control the accumulator vessel liquid level **666** and **746**.

In the drawings, it will be seen that a direct expansion ammonia refrigeration system **385** is described, and which includes a source of liquid ammonia refrigerant **539**; and a direct expansion ammonia evaporator **390** which has a plurality of evaporator tubes **200**, and which are coupled in fluid flowing relation relative to the source of liquid ammonia refrigerant **539**. Yet further, a compressor **490** provides the source of liquid ammonia refrigerant **539** under pressure to the direct expansion ammonia evaporator **390**. Still further, an accumulator vessel **660** defining an internal cavity **659** is provided and which has a liquid region **658**; and a vapor region **661**, which is coupled in downstream fluid flowing relation relative to the direct expansion ammonia evaporator **390**. Still further, this structure **660** is coupled in upstream fluid flowing relation relative to the compressor **490**. The liquid region **658** contains aqueous liquid ammonia **680** received from the respective evaporators **390**. The liquid ammonia **658** and vapor regions **661**, respectively, of the accumulator vessel **660**, are defined, one relative to the other, by an aqueous liquid ammonia level. As earlier described, the accumulator vessel **660** has a minimum aqueous liquid ammonia level **666**, and a maximum aqueous liquid ammonia level **746**. A heat exchanger vessel **662** is provided and coupled in downstream fluid flowing relation relative to the liquid region **658** of the accumulator vessel **660**, and is further coupled in upstream fluid flowing relation relative to the vapor region **661** of the accumulator vessel **660**. The heat exchanger vessel **662** comprises a heating element **690** which vaporizes at least some of the liquid ammonia in the aqueous ammonia refrigerant **680** so as to deliver substantially dry ammonia vapor **657** to the vapor region **661** of the accumulator vessel **660**. Still further, a remaining, acceptably concentrated aqueous ammonia byproduct **733** is produced. The substantially dry ammonia vapor **657** is subsequently delivered to the compressor **490**. A first liquid conduit **663** having a first end **716**, and a second end **718** is provided, and wherein the first end **716** is coupled in fluid flowing relation relative to the liquid region **658** of the accumulator vessel **660**. Still further, the second end **718** is coupled in fluid flowing relation relative to the heat exchanger vessel **662**. The first end **716** is positioned at an elevation below the heat exchanger vessel **662**, and the second end **718** is positioned at an elevation above the heat exchanger vessel **662**. A liquid transfer vessel **664** is provided, and coupled in fluid flowing relation relative to the accumulator vessel **660**, and which regulates the aqueous liquid ammonia level **666/746** of the accumulator vessel **660**. A second fluid conduit **681** is provided having a first end **682** coupled in fluid flowing relation relative to the accumulator vessel **660**; and a second end **683** coupled in fluid flowing relation relative to the liquid transfer vessel **664**. The first end **682** is positioned above the minimum aqueous liquid ammonia level **666**, and below the maximum aqueous liquid ammonia level **746** of the accumulator vessel **660**. Additionally, a high pressure receiver vessel **540** is provided and is coupled in fluid flowing relation relative to the liquid transfer vessel **664**. A plurality of solenoid valves **704/706** are positioned in fluid metering relation therebetween the accumulator vessel **660**, and the liquid transfer vessel **664**, and between the liquid transfer vessel and the high pressure receiver vessel **540**. A controller **702** is provided for controlling the operation of the plurality of solenoid valves **704/706** so as to regulate the aqueous liquid ammonia level **666/746** of the accumulator vessel.

In addition to the foregoing structures described above, the heat exchanger vessel **662** further comprises a drain conduit **731** which removes the remaining acceptably concentrated aqueous ammonia byproduct **733** in the heat exchanger vessel **662** after the heating element **690** vaporizes substantially all of the aqueous liquid ammonia. In the arrangement as seen in the drawings, a drain solenoid valve **730** is positioned in selective fluid metering relation therebetween the heat exchanger vessel **662** and the drain conduit **731**. Still further, a controller **720** is electrically coupled to the drain solenoid **730**, and which further controls the level of aqueous liquid ammonia **680** within the heat exchanger vessel **662**, and which further controls the selective operation of the drain solenoid valve **730** based, at least in part, upon the level of aqueous liquid ammonia **722** within the heat exchanger vessel **662** as measured by a first liquid level sensor **24**, and which is electrically coupled to the controller **720**.

In the arrangement as seen in the drawings, an oil separator **492** is provided and which is coupled in fluid flowing relation therebetween the compressor **490** and the direct expansion ammonia evaporator **390** and which is effective to substantially remove any oil from the liquid ammonia refrigerant **539** before the liquid ammonia refrigerant reaches the evaporator tubes **200**. Additionally, it will be seen from the drawings that a thermostatic expansion valve **400** is positioned downstream of the compressor **490**, and which monitors the temperature and the pressure of the liquid ammonia refrigerant **539** being delivered to the plurality of evaporator tubes **200**. Yet further, a distributor **310** is positioned downstream of the thermostatic expansion valve **400**, and upstream relative to the plurality of evaporator tubes **200**. The thermostatic expansion valve **400** selectively controls the quantity of liquid ammonia refrigerant **539** entering the distributor **310**, based, at least in part, upon the temperature and pressure of the liquid ammonia refrigerant **539**. As seen in the drawings, the distributor **310** distributes the liquid ammonia refrigerant among the plurality of evaporator tubes **200**.

In the arrangement as seen in the drawings, a second liquid level sensor **744** is mounted in liquid level sensing relation relative to the accumulator vessel **660**, and which provides a signal relative to the aqueous liquid ammonia level **666/746**. As seen in the drawings, a controller **702** is electrically coupled to the second liquid level sensor, and which receives the signal. Additionally, a liquid transfer pump **710** is controllably coupled to the controller **702**, and which is further coupled in selective fluid flowing relation relative to the liquid region **658** of the accumulator vessel **660**. Further, a high pressure receiver **540** is provided, and which is coupled in fluid flowing relation relative to the liquid transfer pump **710**. The controller **702** selectively controls the liquid transfer pump **710** to transfer aqueous liquid ammonia **680** between the accumulator vessel **660** and the high pressure receiver **540**, based, at least in part, upon the signal received from the second liquid level sensor **744**, and so as to effectively control the accumulator vessel aqueous liquid ammonia level.

The present invention also includes a method of direct expansion ammonia refrigeration. In this regard, and in its broadest aspect the method includes the steps of providing a source of a substantially non-aqueous liquid ammonia refrigerant **539**; providing a liquid ammonia expansion evaporator **390** which has a plurality of evaporator tubes **200** coupled in fluid receiving relation relative to the source of aqueous liquid ammonia refrigerant, and wherein each of the plurality of evaporator tubes **200** has an inside facing surface **202** which has a wicking structure **205**; and drawing the non-aqueous liquid ammonia refrigerant up onto the inside facing surfaces **202** of the respective evaporator tubes **200** by capillary action by employing the wicking structure **205**. In the invention described above, the method further includes a step of substantially reducing any negative effects relating to boiling heat transfer caused by stratified and/or wavy flow patterns **240** of the liquid ammonia refrigerant **539** within the respective evaporator tubes **200**.

Another aspect of the method of the present invention includes the step of providing a source of a substantially non-aqueous liquid ammonia **539**; and providing a liquid ammonia expansion evaporator **390** which is coupled in fluid flowing relation relative to the source of substantially non-aqueous liquid ammonia. The method further includes the step of supplying the source of the substantially non-aqueous liquid ammonia **539** to the liquid ammonia expansion evaporator; and providing a compressor **490** coupled in upstream fluid flowing relation relative to the liquid ammonia expansion evaporator **390**, and in downstream fluid flowing relation relative to the source of the substantially non-aqueous liquid ammonia **539**. This same method has an additional step of providing an accumulator vessel **660** defining an internal cavity **659** with a liquid region **658** and a vapor region **661**. The vapor region **661** is coupled in downstream fluid flowing relation relative to the direct expansion ammonia evaporator **390**, and is further coupled in upstream fluid flowing relation relative to the compressor **490**. Additionally, this same method includes a step of providing a heat exchanger vessel **662** coupled in downstream fluid flowing relation relative to the liquid region **658** of the accumulator vessel **660**, and in upstream fluid flowing relation relative to the vapor region **661** of the accumulator Vessel **660**. The heat exchanger vessel **662** further includes a heating element **690**. The method includes another step of collecting any aqueous liquid ammonia **680** and any ammonia vapor from the liquid ammonia expansion evaporators **390** into the accumulator vessel **660**, and wherein the ammonia vapor collects in the vapor region **661** of the accumulator vessel, and the aqueous liquid ammonia collects in the liquid region **658** of the accumulator vessel **660**. The method as described above includes another step of transferring the aqueous liquid ammonia **680** from the liquid region **658** of the accumulator vessel **660** to the heat exchanger vessel **662**. The method also includes another step of heating the aqueous liquid ammonia **680** in the heat exchanger vessel **662** to vaporize at least some of the liquid ammonia, and producing a substantially dry ammonia vapor **657**, while leaving an acceptably concentrated aqueous ammonia byproduct **733** in the heat exchanger vessel **662**. The method includes another step of returning the substantially dry vaporized ammonia **657** to the vapor region **661** of the accumulator vessel **660**. Still further, the method includes another step of delivering the substantially dry vaporized ammonia **657** from the vapor region **661** of the accumulator vessel **660** to the compressor **490**.

In the methodology as described above and before the step of collecting any aqueous liquid ammonia **680**, the method further comprises the steps of compressing the substantially dry ammonia vapor **657** delivered from the vapor region **661** of the accumulator vessel **660** with the compressor **490** to form, at least in part, the source of the substantially non-aqueous ammonia liquid **539**, before the step of supplying the substantially non-aqueous ammonia liquid **539** to the liquid ammonia expansion evaporator **390**; and after the step of supplying the substantially non-aqueous ammonia liquid **539** to the liquid ammonia evaporator **390**, boiling all or a substantial quantity of the non-aqueous ammonia liquid **539** within the liquid ammonia expansion evaporator **390** to produce aqueous liquid ammonia **680** and any ammonia vapor. In the methodology as described above, the method includes another step of removing any acceptably concentrated aqueous ammonia byproduct **733** remaining in the heat exchanger vessel **662**. In the methodology as described above, the method includes another step of providing a drain solenoid valve **730** for metering the removal of any acceptably concentrated aqueous ammonia byproduct **733** from the heat exchanger vessel **662**; and providing a controller **720** which is electrically coupled to the drain solenoid valve **730**, and which controls the operation of the drain solenoid valve. Still further, the method includes another step of sensing the level **722** of the aqueous liquid ammonia **680** within the heat exchanger vessel **662**, and producing a signal to the controller **720**; and controlling the level **722** of the aqueous liquid ammonia **680** within the heat exchanger vessel **662** by operating the drain solenoid valve **730** in response to the sensing. In the methodology as described above, the method includes a further step of providing an oil separator **492** which is fluid flowingly coupled intermediate the compressor **490** and the liquid ammonia expansion evaporator **390**; and removing substantially any oil from the source of the non-aqueous liquid ammonia **539** with the oil separator **492** before the non-aqueous liquid ammonia **539** reaches the liquid ammonia expansion evaporator **390**.

Therefore, it will be seen that a direct expansion ammonia evaporation system and a method of direct expansion ammonia refrigeration system provides many advantages over the prior art teachings and practices as seen in FIGS. **1-3** and which has been described earlier in this application. The present invention provides a convenient means whereby a direct expansion ammonia refrigeration system can be fabricated, implemented and operated in a manner not possible heretofore while avoiding the many shortcomings attendant with the prior art practices.

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 within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

I claim:

1. A direct expansion ammonia refrigeration system, comprising:

a source of liquid ammonia refrigerant;

a direct expansion ammonia evaporator having a plurality of evaporation tubes coupled in fluid receiving relation relative to the source of liquid ammonia refrigerant, and which each has an inside facing surface having a wicking structure, and wherein by capillary action, the wicking structure facilitates the drawing of the liquid ammonia refrigerant up and along the inside facing surface of the respective evaporator tubes so as to substantially reduce any stratified and/or wavy flow patterns of the liquid ammonia refrigerant within the respective evaporator tubes;

a compressor coupled to the source of liquid ammonia refrigerant, and which wherein the compressor supplies the liquid ammonia refrigerant to the direct expansion ammonia evaporator;

an accumulator vessel coupled in fluid delivering relation relative to the direct expansion ammonia evaporator and in fluid delivering relation relative to the compressor; and

a heated heat exchanger vessel coupled in both fluid receiving and delivering relation relative to the accumulator vessel, and wherein the heated heat exchanger vessel produces substantially dry ammonia vapor.

2. The direct expansion ammonia refrigeration system as claimed in claim **1**, and wherein the wicking structure comprises a multiplicity of helical grooves formed into the inside facing surface of the evaporator tube, and wherein the helical grooves are dimensioned so as to generate the capillary action.

3. The direct expansion ammonia refrigeration system as claimed in claim **2**, and wherein the helical grooves have a depth of about 0.005 to about 0.05 inches, a spacing of about 0.01 to about 0.10 inches; and a lead angle of about 15 degrees to about 90 degrees.

4. The direct expansion ammonia refrigeration system as claimed in claim **1**, and wherein the wicking structure comprises a multiplicity of cross-hatched knurls formed into the inside facing surface of the respective evaporator tubes, and which are dimensioned so as to generate the capillary action.

5. The direct expansion ammonia refrigeration system as claimed in claim **4**, and wherein the knurls have a length of about 0.005 to about 0.05 inches; a spacing of about 0.01 to about 0.10 inches; and lead angle of about 15 degrees to about 90 degrees.

6. The direct expansion ammonia refrigeration system as claimed in claim **1**, and wherein the wicking structure comprises a sintered metal coating deposited upon the inside facing surface of the respective evaporator tubes, and wherein the sintered metal coating is effective in drawing the liquid ammonia refrigerant up onto the inside facing surface of the respective evaporator tubes by the effect of capillary action.

7. The direct expansion ammonia refrigeration system as claimed in claim **6**, and wherein the sintered metal coating is formed from a metal selected from the group comprising stainless steel; nickel; copper; and/or aluminum.

8. The direct expansion ammonia refrigeration system as claimed in claim **6**, and wherein the sintered metal coating is formed to have a pore radius of about 0.001 to about 0.04 centimeters.

9. The direct expansion ammonia refrigeration system as claimed in claim **1**, and wherein the wicking structure comprises a wire mesh which is telescopingly received within and substantially juxtaposed against the inside facing surface of the respective evaporator tubes.

10. The direct expansion ammonia refrigeration system as claimed in claim **9**, and wherein the wire mesh is formed from a metal selected form the group comprising stainless steel; nickel; copper; and/or aluminum.

11. The direct expansion ammonia refrigeration system as claimed in claim **7**, and wherein the wire mesh has a mesh size ranging from about 60 to about 450 openings per inch.

12. A direct expansion ammonia refrigeration system, comprising:

a source of liquid ammonia refrigerant;

a direct expansion ammonia evaporator having at least one evaporator tube for receiving the source of liquid ammonia refrigerant, and which has an inside facing surface which acts upon the liquid ammonia refrigerant so as to substantially reduce any stratified and/or wavy flow patterns of the liquid ammonia refrigerant within the at least one evaporator tube;

a compressor coupled to, and operable to deliver the source of liquid ammonia refrigerant to the direct expansion ammonia evaporator;

an accumulator vessel having an internal liquid region which contains aqueous liquid ammonia received from the direct expansion evaporator, and wherein the accumulator vessel further has a vapor region which is coupled in fluid flowing relation relative the compressor; and

a heated heat exchanger vessel for vaporizing aqueous ammonia received from the liquid region of the accumulator vessel so as to generate substantially dry ammonia vapor, and wherein the substantially dry ammonia vapor is delivered to the compressor.

13. The direct expansion ammonia refrigeration system as claimed in claim **12**, and further comprising;

a wicking structure made integral with the inside facing surface of the evaporator tube, and wherein the wicking structure, through capillary action, draws the liquid ammonia up and along the inside facing surface.

14. The direct expansion ammonia refrigeration system as claimed in claim **13**, and wherein the wicking structure further comprises a multiplicity of helical grooves, and wherein the helical grooves are dimensioned to generate the desired capillary action.

15. The direct expansion ammonia refrigeration system as claimed in claim **14**, and wherein the helical grooves have a depth of about 0.005 to about 0.05 inches, a spacing of about 0.01 to about 0.1 inches, and a lead angle of about 15 degrees to about 90 degrees.

16. The direct expansion refrigeration system as claimed in claim **13**, and wherein the wicking structure comprises a multiplicity of elevated structures, and wherein the multiplicity of elevated structures, in combination with capillary action, reduces the stratified and/or wavy flow patterns of the liquid ammonia refrigerant in the evaporator tube.

17. The direct expansion refrigeration system as claimed in claim **13**, and wherein the wicking structure comprises a multiplicity of cross-hatched knurls which are formed into the inside facing surface.

18. The direct expansion refrigeration system as claimed in claim **13**, and wherein the wicking structure comprises a sintered metal coating, and wherein the sintered metal coating is effective in causing the desired capillary action.

19. The direct expansion refrigeration system as claimed in claim **13**, and wherein the wicking structure comprises a wire mesh, and wherein the wire mesh is received within, and juxtaposed relative to, the inside facing surface of the evaporator tube.

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