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(71) Applicant: **Carrier Corporation**
Jupiter, FL 33478 (US)

(72) Inventors:
- **RANJAN, Rajiv**
East Hartford, CT Connecticut 06108 (US)
- **FENG, Yinshan**
East Hartford, CT Connecticut 06108 (US)
- **CORDATOS, Haralambos**
East Hartford, CT Connecticut 06108 (US)
- **VERMA, Parmesh**
East Hartford, CT Connecticut 06108 (US)
- **DARDAS, Zissis A.**
East Hartford, CT Connecticut 06108 (US)

(74) Representative: **Schmitt-Nilson Schraud Waibel Wohlfrom**
Patentanwälte Partnerschaft mbB
Pelkovenstraße 143
80992 München (DE)

(54) **REFRIGERANT PURGE SYSTEM WITH MEMBRANE PROTECTION**

(57) Disclosed is a refrigeration system including a heat transfer fluid circulation loop configured to allow a refrigerant to circulate through the circulation loop. A purge gas outlet is in operable communication with the heat transfer fluid circulation loop. The system also includes at least one gas permeable membrane having a first side in operable communication with the purge gas outlet and a second side. The membrane includes a separation layer including a porous inorganic material with pores of a size to allow passage of contaminants through the membrane and restrict passage of the through the membrane, and a polymer coating over the separation layer. A permeate outlet is in operable communication with the second side of the membrane.

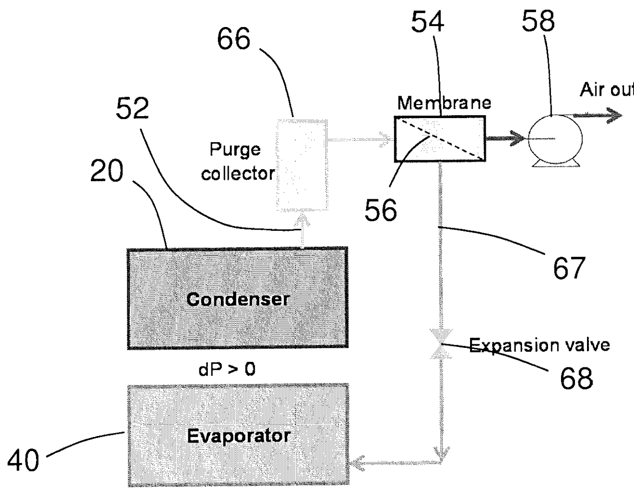

FIG. 4

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Description

BACKGROUND

[0001] This disclosure relates generally to chiller systems used in air conditioning systems, and more particularly to a purge system for removing contaminants from a refrigeration system.

[0002] Chiller systems such as those utilizing centrifugal compressors may include sections that operate below atmospheric pressure. As a result, leaks in the chiller system may draw air into the system, contaminating the refrigerant. This contamination degrades the performance of the chiller system. To address this problem, existing low pressure chillers include a purge unit to remove contamination. Existing purge units use a vapor compression cycle to separate non-condensable gas from the refrigerant. Existing purge units are complicated and lose refrigerant in the process of removing contamination.

BRIEF DESCRIPTION

[0003] Disclosed is a refrigeration system including a heat transfer fluid circulation loop configured to allow a refrigerant to circulate therethrough. A purge gas outlet is in operable communication with the heat transfer fluid circulation loop. The system also includes at least one gas permeable membrane having a first side in operable communication with the purge gas outlet and a second side. The membrane includes a separation layer including a porous inorganic material with pores of a size to allow passage of contaminants through the membrane and restrict passage of the refrigerant through the membrane, and a polymer coating over the separation layer. A permeate outlet is in operable communication with the second side of the membrane.

[0004] In some embodiments, the system further includes a prime mover operably coupled to the permeate outlet, and the prime mover is configured to move gas from the second side of the membrane to an exhaust port leading outside the fluid circulation loop.

[0005] In any one or combination of the foregoing embodiments, the heat transfer fluid circulation loop includes a compressor, a heat rejection heat exchanger, an expansion device, and a heat absorption heat exchanger, connected together in order by conduit, and the purge gas outlet is in operable communication with at least one of the heat rejection heat exchanger, the heat absorption heat exchanger, or the membrane.

[0006] In any one or combination of the foregoing embodiments, the system further includes a retentate return conduit operably coupling the first side of the membrane to the fluid circulation loop. In some embodiments, the prime mover is a vacuum pump.

[0007] In any one or combination of the foregoing embodiments, the system further includes a purge gas collector operably coupled to the purge outlet and the membrane.

[0008] In some embodiments, the system further includes a prime mover operably coupled to the permeate outlet, the prime mover configured to move gas from the second side of the membrane to an exhaust port leading outside the fluid circulation loop. In some embodiments, the prime mover includes a vacuum pump in operable communication with the second side of the membrane.

[0009] In any one or combination of the foregoing embodiments, the system further includes a filter in operable communication with the purge outlet and the first side of the membrane.

[0010] In any one or combination of the foregoing embodiments, the separation layer includes a ceramic material.

[0011] In any one or combination of the foregoing embodiments, wherein the membrane includes zeolite.

[0012] In any one or combination of the foregoing embodiments, the at least one gas permeable membrane includes a plurality of gas permeable membranes; wherein the plurality of gas permeable membranes are arranged in serial or parallel communication.

[0013] In any one or combination of the foregoing embodiments, the polymer layer includes a polymer selected from a silicone rubber, fluorosilicone or polyimide.

[0014] In any one or combination of the foregoing embodiments, the polymer layer has a thickness of 0.05 μm to 50 μm.

[0015] In any one or combination of the foregoing embodiments, the system further includes a controller configured to operate the fluid circulation loop in response to a cooling demand signal and to operate the prime mover in response to a determination of contaminants in the fluid circulation loop.

[0016] In any one or combination of the foregoing embodiments, the controller is configured to activate a purge back-flush mode in which gas is transported from the second side of the membrane to the first side of the membrane.

[0017] In any one or combination of the foregoing embodiments, the controller is configured to activate a heat source to heat the membrane to a temperature to remove contaminants.

[0018] Also disclosed is a method of operating a refrigeration system, comprising circulating a refrigerant through a heat transfer fluid circulation loop in response to a cooling demand signal. Purge gas comprising contaminants is collected from a purge outlet in the fluid circulation loop. The contaminants are transferred across a permeable molecular sieve membrane with a prime mover, said membrane comprising a porous inorganic or metal organic framework with pores of a size to allow passage of the contaminants through the membrane and restrict passage of the refrigerant through the membrane. The method also includes periodically back-flushing the membrane by transporting gas from the second side of the membrane to the first side of the membrane, or periodically heating the membrane to a temperature to remove contaminants, or both periodically transporting gas from the second side of the membrane to the first side of the membrane and periodically heating the membrane to a temperature to remove contaminants.

[0019] In any one or combination of the foregoing embodiments, the method includes periodically back-flushing the membrane by transporting gas from the second side of the membrane to the first side of the membrane.

[0020] In any one or combination of the foregoing embodiments, the method also includes periodically heating the membrane to a temperature to remove contaminants.

[0021] In any one or combination of the foregoing embodiments, the method also includes passing the purge gas through a filter before reaching the membrane.

[0022] In any one or combination of the foregoing embodiments, the method also includes transporting the contaminants through a polymer coating on the inorganic or metal organic framework membrane.

[0023] In any one or combination of the foregoing embodiments, the method also includes collecting the purge gas in a purge gas collector between the purge outlet and the membrane.

[0024] In any one or combination of the foregoing embodiments, the method also includes returning refrigerant from the first side of the membrane to the fluid circulation loop.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1 is a schematic depiction of a refrigeration system including a vapor compression heat transfer refrigerant fluid circulation loop;

FIG. 2 is a schematic depiction of an example embodiment of a membrane purge system for a refrigeration system;

FIG. 3 is a schematic depiction of a separation membrane;

FIG. 4 is a schematic depiction of an example embodiment of a membrane purge system with purge collector and relevant components of a vapor compression heat transfer refrigerant fluid circulation loop; and

FIG. 5 is a schematic depiction of another example embodiment of a membrane purge system with purge collector and relevant components of a vapor compression heat transfer refrigerant fluid circulation loop.

DETAILED DESCRIPTION

[0026] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0027] With reference to FIG. 1, a heat transfer fluid circulation loop such as can be used in a chiller is shown in block diagram form in FIG. 1. As shown in FIG. 1, a compressor 10 pressurizes heat transfer fluid in its gaseous state, which both heats the fluid and provides pressure to circulate it throughout the system. In some embodiments, the heat transfer fluid, or refrigerant, comprises an organic compound. In some embodiments, the refrigerant comprises a hydrocarbon or substituted hydrocarbon. In some embodiments, the refrigerant comprises a halogen-substituted hydrocarbon. In some embodiments, the refrigerant comprises a fluoro-substituted or chloro-fluoro-substituted hydrocarbon. The hot pressurized gaseous heat transfer fluid exiting from the compressor 10 flows through conduit 15 to heat exchanger condenser 20, which functions as a heat exchanger to transfer heat from the heat transfer fluid to the surrounding environment, resulting in condensation of the hot gaseous heat transfer fluid to a pressurized moderate temperature liquid. The liquid heat transfer fluid exiting from the condenser 20 flows through conduit 25 to expansion valve 30, where the pressure is reduced. The reduced pressure liquid heat transfer fluid exiting the expansion valve 30 flows through conduit 35 to heat exchanger evaporator 40, which functions as a heat exchanger to absorb heat from the surrounding environment and boil the heat transfer fluid. Gaseous heat transfer fluid exiting the evaporator 40 flows through conduit 45 to the compressor 10, thus completing the heat transfer fluid loop. The heat transfer system has the effect of transferring heat from the environment surrounding the evaporator 40 to the environment surrounding the condenser 20. The thermodynamic properties of the heat transfer fluid must allow it to reach a high enough temperature when compressed so that it is greater than the environment surrounding the condenser 20, allowing heat to be transferred to the surrounding environment. The thermodynamic properties of the heat transfer fluid must also have a boiling point at its post-expansion pressure that allows the temperature surrounding the evaporator 40 to provide heat to vaporize the liquid heat transfer fluid.

[0028] With reference now to FIG. 2, there is shown an example embodiment of a purge system that can be connected to a vapor compression heat transfer fluid circulation loop such as FIG. 1. As shown in FIG. 2, the purge system receives gas comprising refrigerant gas and contaminants (e.g., nitrogen, oxygen, water vapor) through a connection 52 to a membrane separator 54 on a first side of a membrane 56. A prime mover such as a vacuum pump 58 connected to the membrane separator 54 through connection 60 provides a driving force to pass the contaminants through the membrane 56 and exit the system from a second side of the membrane 56 through an outlet 62. In some embodiments, the prime mover can be in the fluid loop, e.g., a refrigerant pump or compressor. Refrigerant gas remains on the first side of the membrane 56 and can return to the fluid circulation loop through connection 64.

[0029] The membrane 56 comprises a porous inorganic material. Examples of porous inorganic materials can include ceramics such as metal oxides or metal silicates, more specifically aluminosilicates (e.g., Chabazite Framework (CHA) zeolite, Linde type A (LTA) zeolite, porous carbon, porous glass, clays (e.g., Montmorillonite, Halloysite). Porous inorganic materials can also include porous metals such as platinum and nickel. Hybrid inorganic-organic materials such as a metal organic framework (MOF) can also be used. Other materials can be present in the membrane such as a carrier in which a microporous material can be dispersed, which can be included for structural or process considerations.

[0030] Metal organic framework materials comprise metal ions or clusters of metal ions coordinated to organic ligands to form one-, two- or three-dimensional structures. A metal-organic framework can be characterized as a coordination network with organic ligands containing voids. The coordination network can be characterized as a coordination compound extending, through repeating coordination entities, in one dimension, but with cross-links between two or more individual chains, loops, or spiro-links, or a coordination compound extending through repeating coordination entities in two or three dimensions. Coordination compounds can include coordination polymers with repeating coordination entities extending in one, two, or three dimensions. Examples of organic ligands include, but are not limited to, bidentate carboxylates (e.g., oxalic acid, succinic acid, phthalic acid isomers, etc.), tridentate carboxylates (e.g., citric acid, trimesic acid), azoles (e.g., 1,2,3-triazole), as well as other known organic ligands. A wide variety of metals can be included in a metal organic framework. Examples of specific metal organic framework materials include but are not limited to zeolitic imidazole framework (ZIF), HKUST-1.

[0031] In some embodiments, pore sizes can be characterized by a pore size distribution with an average pore size from 2.5 Å to 10.0 Å, and a pore size distribution of at least 0.1 Å. In some embodiments, the average pore size for the porous material can be in a range with a lower end of 2.5 Å to 4.0 Å and an upper end of 2.6 Å to 10.0 Å. Å. In some embodiments, the average pore size can be in a range having a lower end of 2.5 Å, 3.0 Å, 3.5 Å, and an upper end of 3.5 Å, 5.0 Å, or 6.0 Å. These range endpoints can be independently combined to form a number of different ranges, and all ranges for each possible combination of range endpoints are hereby disclosed. Porosity of the material can be in a range having a lower end of 5 %, 10 %, or 15 %, and an upper end of 85 %, 90 %, or 95 % (percentages by volume). These range endpoints can be independently combined to form a number of different ranges, and all ranges for each possible combination of range endpoints are hereby disclosed.

[0032] The above microporous materials can be can be synthesized by hydrothermal or solvothermal techniques (e.g., sol-gel,) where crystals are slowly grown from a solution. Templating for the microstructure can be provided by a secondary building unit (SBU) and the organic ligands. Alternate synthesis techniques are also available, such as physical vapor deposition or chemical vapor deposition, in which metal oxide precursor layers are deposited, either as a primary microporous material, or as a precursor to an MOF structure formed by exposure of the precursor layers to sublimed ligand molecules to impart a phase transformation to an MOF crystal lattice.

[0033] In some embodiments, the above-described inorganic or MOF membrane materials can provide a technical effect of promoting separation of contaminants (e.g., nitrogen, oxygen, or water molecules) from refrigerant gas, and low refrigerant loss. Other membrane materials, such as porous and non-porous polymers can be subject to solvent interaction with the matrix material, which can interfere with effective separation. In some embodiments, the capabilities of the materials described herein can provide a technical effect of promoting the implementation of various example embodiments of refrigeration systems with purge, as described in more detail with reference to the example embodiments below. For example, non-porous polymers are typically used as membranes in air separation, operating on a mechanism known as "solution-diffusion", whereby molecules are separated by first dissolving into the polymer matrix and then diffusing at different rates across the membrane layer. In most instances, separation is accomplished based on differences in the size of the molecules. However, while refrigerant molecules are much larger than non-condensable air and water vapor molecules, they have been found to have very high solubility into such polymer films, which results in lower separation factors than anticipated based on molecular size.

[0034] As mentioned above, the microporous molecular sieve material can be disposed on a gas permeable inorganic porous support such as alumina or zirconia, or other porous ceramic or metallic (e.g., Fe, Ni) material. Thickness of the support can range from 10 μm to 10 mm, more specifically from 100 nm to 750 nm, and even more specifically from 250 nm to 500 nm. In the case of tubular membranes 70 as described in FIG. 3, fiber diameters can range from 0.1 mm to 100 mm, and fiber lengths can range from 0.02 m to 2 m.

[0035] In some embodiments, the microporous material can be deposited on the support as particles in a powder or dispersed in a liquid carrier using various techniques such as spray coating, dip coating, solution casting, etc. The dispersion can contain various additives, such as dispersing aids, rheology modifiers, etc. Polymeric additives can be used; however, a polymer binder is not needed, although a polymer binder can be included and in some embodiments is included. However, a polymer binder present in an amount sufficient to form a contiguous polymer phase can provide passageways in the membrane for larger molecules to bypass the molecular sieve particles. Accordingly, in some embodiments a polymer binder is excluded. In other embodiments, a polymer binder can be present in an amount below that needed to form a contiguous polymer phase, such as embodiments in which the membrane is in series with other membranes that may be more restrictive. In some embodiments, particles of the microporous material (e.g., particles with effective diameter of 0.01 μm to 10 mm, or in some embodiments from 0.5 μm to 10 μm, can be applied as a powder or dispersed in a liquid carrier (e.g., an organic solvent or aqueous liquid carrier) and coated onto the support followed by removal of the liquid. In some embodiments, the application of solid particles of microporous material from a liquid composition to the support surface can be assisted by application of a pressure differential across the support. For example a vacuum can be applied from the opposite side of the support as the liquid composition comprising the solid microporous particles to assist in application of the solid particles to the surface of the support.

[0036] In some exemplary embodiments, the layer is applied with a vacuum enhanced dip coating process where a surface of the support is contacted with a liquid dispersion of the microporous material dispersion while a vacuum is applied from the opposite side of the support (or in the case of hollow tube membrane configuration of FIG. 3, the tubular support 72 can be immersed in the liquid except for the open ends). The vacuum will draw solvent from the dispersion through the porous support, resulting in deposition of the microporous particles onto the support. In the case of hollow fiber membranes as shown in FIG. 3, this vacuum filtration technique can be particularly effective, as the hollow core 76 provides an enclosed space from which to draw a vacuum without the necessity of a vacuum frame or similar structure that would be needed for a flat or planar membrane configuration.

[0037] After coating a layer of microporous particles onto the support, the layer can be dried to remove residual solvent and optionally heated to fuse the microporous particles together into a contiguous layer. Exemplary heating conditions can be in a range having at temperatures of at least 50°C, 75°C, or 100°C, more specifically from 20°C to 75°C, and even more specifically from 20°C to 50°C.

[0038] Various membrane structure configurations can be utilized, including but not limited to, flat or planar configurations, tubular configurations, or spiral configurations. An example embodiment of a tubular configuration is schematically depicted in FIG. 3. As shown in FIG. 3, a tubular membrane 70 comprises a porous support configured as tubular shell 72 surrounded by a molecular sieve layer 74. Thickness of the molecular sieve layer can range from 2 nm to 500 nm, more specifically from 2 nm to 100 nm, and even more specifically from 2 nm to 50 nm. The shell 72 defines a hollow core 76 that is open at both ends. In some embodiments, multiple tubular membranes are disposed together in a tube bank with a header (not shown) at each end in fluid communication with the hollow cores 76. In use, purge gas comprising refrigerant gas and contaminants is delivered to the exterior of the membrane 70 at a greater pressure than that inside the hollow cores 76 (e.g., by drawing a vacuum on the hollow cores 76 through the headers). This pressure differential provides a driving force for non-condensable nitrogen, oxygen or water molecules to pass through the molecular sieve layer while the larger refrigerant molecules are restricted from passage through the molecular sieve layer 74.

[0039] In some embodiments, the microporous material can be configured as nanoplatelets such as zeolite nanosheets. Zeolite nanosheet particles can have thicknesses ranging from 2 to 50 nm, more specifically 2 to 20 nm, and even more specifically from 2 nm to 10 nm. The mean diameter of the nanosheets can range from 50 nm to 5000 nm, more specifically from 100 nm to 2500 nm, and even more specifically from 100 nm to 1000 nm. Mean diameter of an irregularly-shaped tabular particle can be determined by calculating the diameter of a circular-shaped tabular particle having the same surface area in the x-y direction (i.e., along the tabular planar surface) as the irregularly-shaped particle. Zeolite such as zeolite nanosheets can be formed from any of various zeolite structures, including but not limited to, framework type MFI, MWW, FER, LTA, FAU, and mixtures of the preceding with each other or with other zeolite structures. In a more specific group of exemplary embodiments, the zeolite such as zeolite nanosheets can comprise zeolite structures selected from MFI, MWW, FER, LTA framework type. Zeolite nanosheets can be prepared using known techniques such as exfoliation of zeolite crystal structure precursors. For example, MFI and MWW zeolite nanosheets can be prepared by sonicating the layered precursors (multilamellar silicalite-1 and ITQ-1, respectively) in solvent. Prior to sonication, the zeolite layers can optionally be swollen, for example with a combination of base and surfactant, and/or melt-blending with polystyrene. The zeolite layered precursors are typically prepared using conventional techniques for preparation of microporous materials such as sol-gel methods.

[0040] With reference again to FIG. 3, a polymer coating 78 is disposed over the molecular sieve layer 74. The polymer can be virtually any type of polymer that is resistant to erosion by the refrigerant as a solvent and is capable of being coated onto the molecular sieve layer, including but not limited to silicone polymers (i.e., polysiloxanes), fluorosilicones, or polyimides. The polymer coating can be applied by any technique including but not limited to spray coating, dip coating, roll coating, or extrusion, followed by curing of the polymer coating. In some embodiments, the polymer coating 78 can be permeable to both refrigerant gas and the contaminants, through either or both of porosity sieving or polymer solvent effects. In some embodiments, the polymer coating 78 can allow for passage of both types of gases via a solution-diffusion mechanism. In some embodiments, the polymer coating can have a thickness in a range with a lower end of 0.05 μm, 0.1 μm, 0.5 μm, and an upper end of 4 μm, 10 μm, or 50 μm. These range endpoints can be independently combined to form a number of different ranges, and all ranges for each possible combination of range endpoints are hereby disclosed. In some embodiments, the polymer coating can provide a technical effect of protecting the molecular sieve layer 74 from exposure to contaminants such as oils, or to physical damage. In some embodiments, the polymer coating can provide a technical effect of reducing leakage of refrigerant across the membrane through pinholes. Although the polymer coating may not be impervious to refrigerant molecules, it can fill in any pinholes and significantly reduce the rate of mass transfer through any such pinholes. The inorganic layer 74 may also contain grain boundaries, through which larger refrigerant molecules can pass, which reduces the layer's selectivity. The polymer coating can mask such grain boundaries, thereby reducing refrigerant permeance through the membrane.

[0041] With reference now to FIG. 4, another purge system is shown along with selected components of the refrigerant fluid circulation loop of FIG. 1. As shown in FIG. 4, a purge collector 66 receives gas vented from the condenser 20. In some embodiments, the connection of the vent line to the condenser can be made at a high point of the condenser structure. In some embodiments, the purge collector can provide a technical effect of promoting higher concentrations of contaminants at the membrane, which can promote more effective mass transfer and separation. This effect can occur through a stratification of gas in the purge collector in which lighter contaminants concentrate toward the top of the purge collector and heavier refrigerant gas concentrates toward the bottom of the purge collector. In some embodiments, the purge collector 66 can be any kind of vessel or chamber with a volume or cross-sectional open space to provide for collection of purge gas and for a low gas velocity during operation of the purge system vacuum pump 58 to promote stratification. Stratification can also occur at any time when the purge system is not operating (including during operation of the refrigeration system fluid circulation loop), as the purge collector 66 remains in fluid communication with the condenser vent line with essentially stagnant gas in the purge collector. Other embodiments can also be employed to promote higher concentrations of contaminants at the membrane separator 54, as discussed in more detail below.

[0042] In some embodiments, refrigerant from the first side of membrane 56 can be returned to the refrigerant fluid circulation loop. As shown in FIG. 4, a connection 67 returns retentate gas from the first side of membrane 56 to the refrigerant fluid circulation loop at the evaporator 40, through a control device such as expansion valve 68 utilized to accommodate the pressure differential between the first side of the membrane 56 (which is close to the pressure at the condenser 20) and pressure at the evaporator 40. It should be noted that the control device can control either or both flow through or pressure drop across the control device, and expansion valve 68 is shown as an integrated control device unit that performs both functions for ease of illustration, but could be separate components such as a control valve and an expansion orifice. In some embodiments, utilization of a bypass refrigerant return can provide a technical effect of promoting greater concentrations of contaminants at the first side of membrane 56 by removing gas at the membrane 56 that is concentrated with refrigerant after removal of contaminant gas molecules through the membrane 56, so that refrigerant-concentrated gas can be displaced with gas from the purge collector 66 that has a higher concentration of contaminants. The connection 67 can also include a control or shut-off valve, which can be integrated with an expansion device (i.e., an expansion valve), as described in more detail in US patent application Serial No. 62/584,012, the disclosure of which is incorporated herein by reference in its entirety. In alternative embodiments (not shown), the bypass conduit 67 can return refrigerant-laden gas to a colder side of the condenser 20 or inlet of the compressor 10, in which case an expansion device may not be needed due to lower pressure differential compared to that of a bypass return to the evaporator 40. In such as case, the connection 67 can utilize a control device such as a control or shut-off valve 68 that does not provide gas expansion. Other system variations such as centrifugal separators or chilling coils integrated with a purge chamber, pumped recycle of permeate back to the retentate (upstream) side of the membrane, cascaded multiple membranes, or alternative prime movers such as a thermal prime mover or a pump or compressor in the fluid circulation loop, are described in more detail in US patent application Serial No._/_, entitled "Refrigeration Purge System", filed on even date herewith under attorney docket number 98251US01 (U301399US), the disclosure of which is incorporated herein by reference in its entirety.

[0043] Additional embodiments can also be employed to protect or promote durability of the membrane. For example, in some embodiments a controller (not shown) in operative communication with various sensing and control components of the system can be configured to periodically activate a purge backflush in which gas is transported from the second (i.e., permeate) side of the membrane to the first (i.e., retentate) side of the membrane. As used herein, "periodically" means that activation can be based on any sort of criteria including human operator activation, or predetermined criteria including but not limited to the passage of time, accumulated system operating time, accumulated system purge cycle time, or measured system criteria such as measured pressure differential across the membrane during purge cycle operation of the prime mover. The backflush mode can be activated by isolating the membrane separator 54 from the purge collector 66 and reversing the direction of the driving force. For example, in the example embodiments of FIGS. 4-5, this can be accomplished by switching a 3-way valve (not shown) in the conduit between the purge collector 66 and the membrane separator 54 to simultaneously connect a bypass line (not shown) from the three-way valve connecting the suction side of the vacuum pump 58 and the first side of the membrane 56 while isolating the first side of the membrane 56 from the purge collector 66. A similar 3-way valve connection can be employed at the suction side of the vacuum pump 58 to redirect the vacuum pump connection between the second side of the membrane 56 or to the bypass line to the first side of the membrane 56. In some embodiments, the controller can be configured to periodically expose the membrane 56 to heat to remove contaminants such as oil. In some embodiments, the membrane can be heated to at least 200°C, or to at least 300°C, or to at least 400°C. Heating can generally be kept under 200°C in order to prevent degradation of the polymer layer 78, save energy and simplify thermal management.

[0044] In some embodiments, durability and protection of the membrane 56 can be promoted by a filter such as a coalescing filter, moisture filter, or particulate filter between the purge outlet and the membrane 56. In the example embodiment shown in FIG. 5, a coalescing filter 79 is disposed in the gas flow path between the purge collector 66 and the membrane separator 54. One type of coalescing filter can have a cylindrical inner rigid open mesh core (e.g., stainless steel) around which a fiber coalescing medium (e.g., borosilicate glass fiber) is disposed. In some embodiments, the coalescing medium can have a gradient pore structure by using layers of increasing pore size. The inlet gas first encounters the smallest pores, which increase with penetration distance to allow more space as the coalesced droplets grow. The coalescing medium can be supported by an outer mesh structure to provide mechanical strength which is then followed by a coarse outer wrap that serves as a drainage zone. Gas flows into the hollow core of the cylinder and then radially outward through the filter media. Tiny liquid droplets are captured by the inner filter media and coalesce into larger liquid droplets that are captured and removed in the radially outward drainage zone.

[0045] The term "about", if used, is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application. For example, "about" can include a range of ± 8% or 5%, or 2% of a given value.

[0046] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0047] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

Claims

1. A refrigeration system comprising
a heat transfer fluid circulation loop configured to allow a refrigerant to circulate therethrough;
a purge gas outlet in operable communication with the heat transfer fluid circulation loop;
at least one gas permeable membrane having a first side in operable communication with the purge gas outlet and a second side, said membrane comprising a separation layer comprising a porous inorganic material with pores of a size to allow passage of contaminants through the membrane and restrict passage of the refrigerant through the membrane, and a polymer coating over said separation layer; and
a permeate outlet in operable communication with the second side of the membrane.

2. The refrigeration system of claim 1, further comprising a prime mover operably coupled to the permeate outlet, the prime mover configured to move gas from the second side of the membrane to an exhaust port leading outside the fluid circulation loop.

3. The refrigeration system of claim 1, wherein the heat transfer fluid circulation loop comprises a compressor, a heat rejection heat exchanger, an expansion device, and a heat absorption heat exchanger, connected together in order by conduit;
wherein the purge gas outlet is in operable communication with at least one of the heat rejection heat exchanger, the heat absorption heat exchanger, or the membrane.

4. The refrigeration system of claim 2 wherein the prime mover comprises a vacuum pump in operable communication with the second side of the membrane.

5. The refrigeration system of any of claims 1-4, further comprising a filter in operable communication with the purge outlet and the first side of the membrane.

6. The refrigeration system of any preceding claim, wherein the separation layer comprises a ceramic material, particularly zeolite.

7. The refrigeration system of any preceding claim, wherein the at least one gas permeable membrane comprises a plurality of gas permeable membranes; wherein the plurality of gas permeable membranes are arranged in serial or parallel communication.

8. The refrigeration system of any preceding claim, wherein the polymer layer comprises a polymer selected from a silicone rubber, fluorosilicone or polyimide.

9. The refrigeration system of any preceding claim, wherein the polymer layer has a thickness of 0.05 μm to 50 μm.

10. The refrigeration system of any preceding claim, further comprising a controller configured to operate the fluid circulation loop in response to a cooling demand signal and to operate the prime mover in response to a determination of contaminants in the fluid circulation loop.

11. The refrigeration system of claim 10, wherein the controller is configured to activate a purge back-flush mode in which gas is transported from the second side of the membrane to the first side of the membrane.

12. The refrigeration system of claims 10 or 11, wherein the controller is configured to activate a heat source to heat the membrane to a temperature to remove contaminants.

13. A method of operating a refrigeration system, comprising
circulating a refrigerant through a heat transfer fluid circulation loop in response to a cooling demand signal;
collecting purge gas comprising contaminants from a purge outlet in the fluid circulation loop;
transferring the contaminants across a permeable molecular sieve membrane with a prime mover, said membrane comprising a porous inorganic or metal organic framework with pores of a size to allow passage of the contaminants through the membrane and restrict passage of the refrigerant through the membrane; and
periodically back-flushing the membrane by transporting gas from the second side of the membrane to the first side of the membrane, or periodically heating the membrane to a temperature to remove contaminants, or both periodically transporting gas from the second side of the membrane to the first side of the membrane and periodically heating the membrane to a temperature to remove contaminants.

14. The method of claim 13, comprising
periodically back-flushing the membrane by transporting gas from the second side of the membrane to the first side of the membrane; and/or
periodically heating the membrane to a temperature to remove contaminants.

15. The method of claim 13 or 14, further comprising
passing the purge gas through a filter before reaching the membrane; and/or
transporting the contaminants through a polymer coating on the inorganic or metal organic framework membrane; and/or
collecting the purge gas in a purge gas collector between the purge outlet and the membrane; and/or
returning refrigerant from the first side of the membrane to the fluid circulation loop.

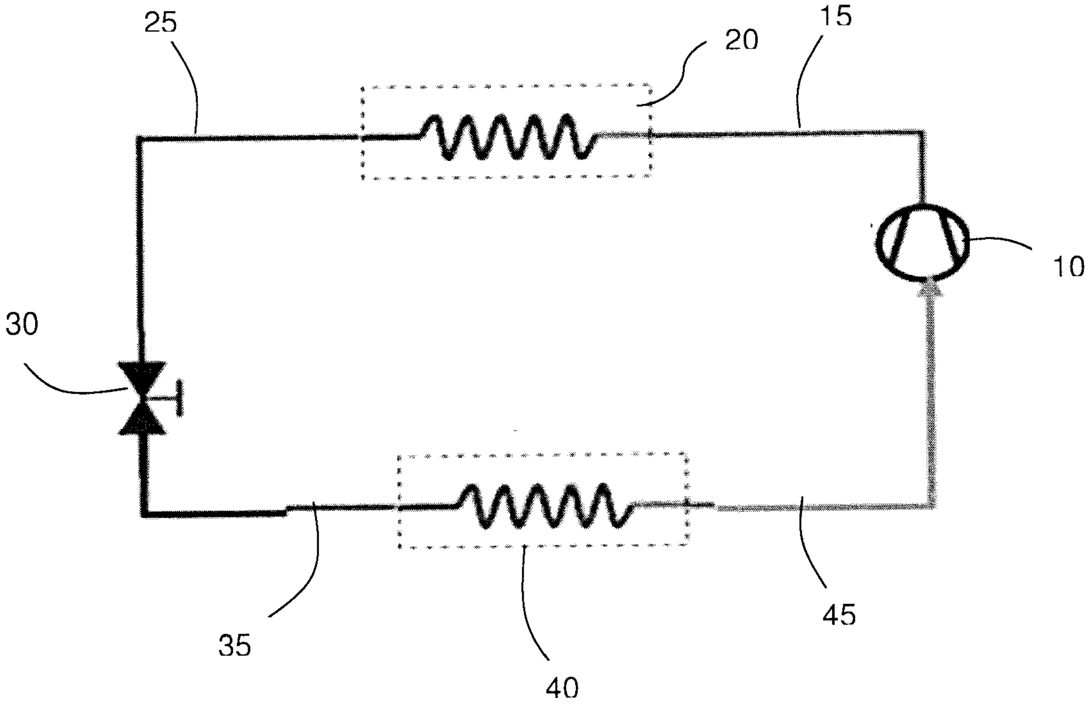

FIG. 1

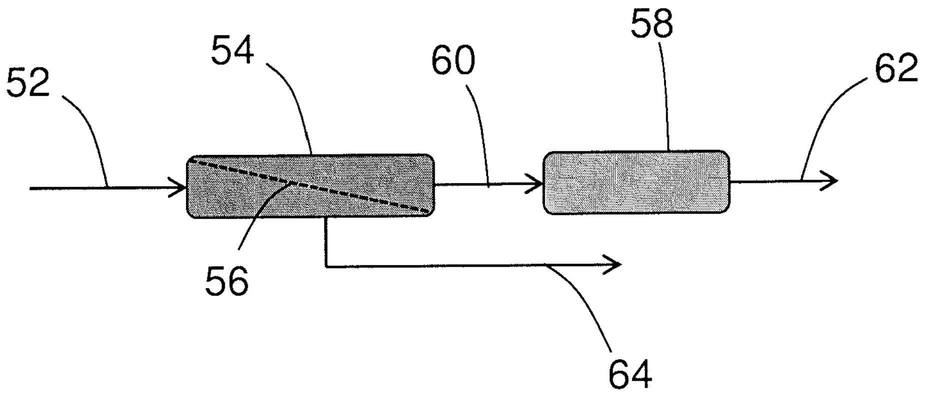

FIG. 2

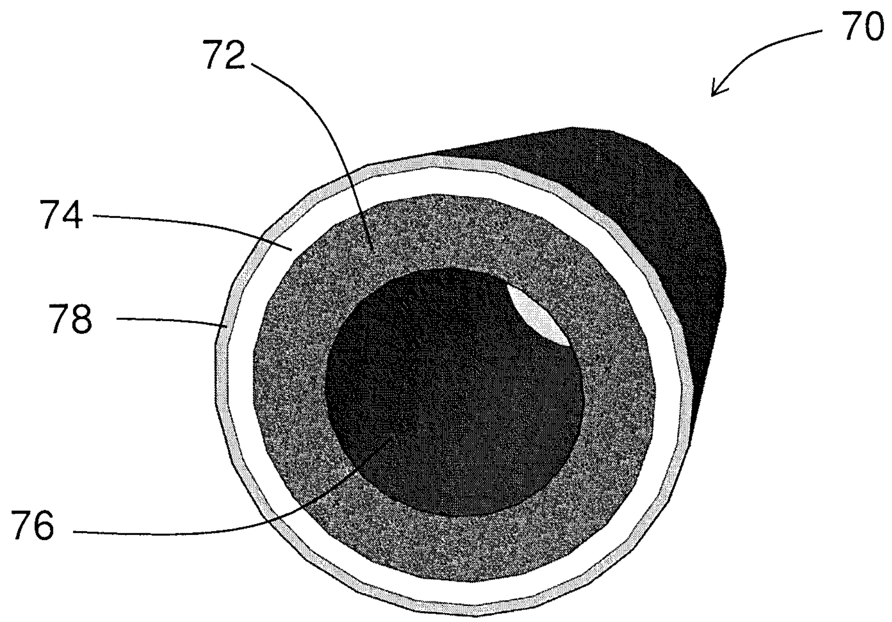

FIG. 3

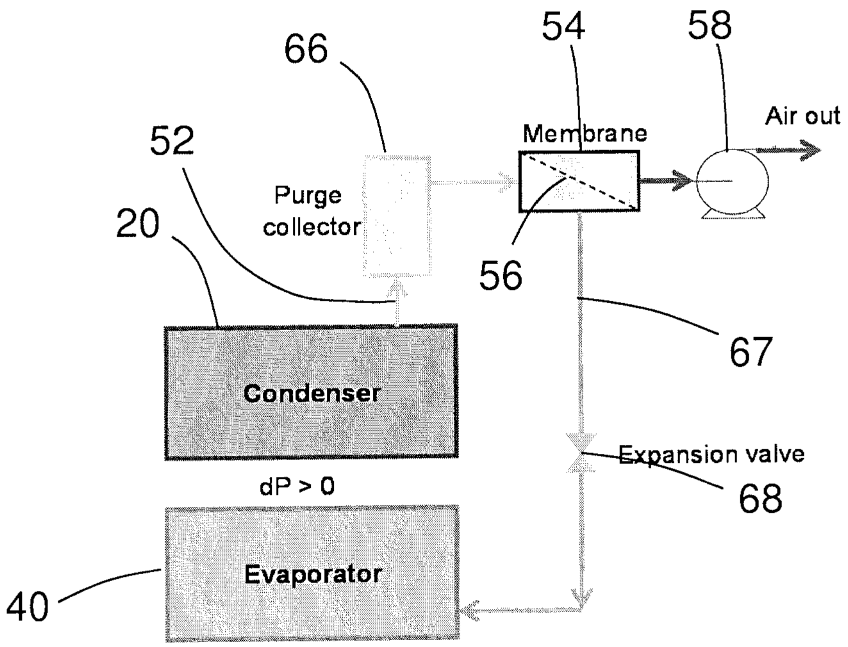
66
52
20
54
58
Membrane
Air out
Purge
collector
56
67
Condenser
Expansion valve
68
dP > 0
Evaporator
40

FIG. 4

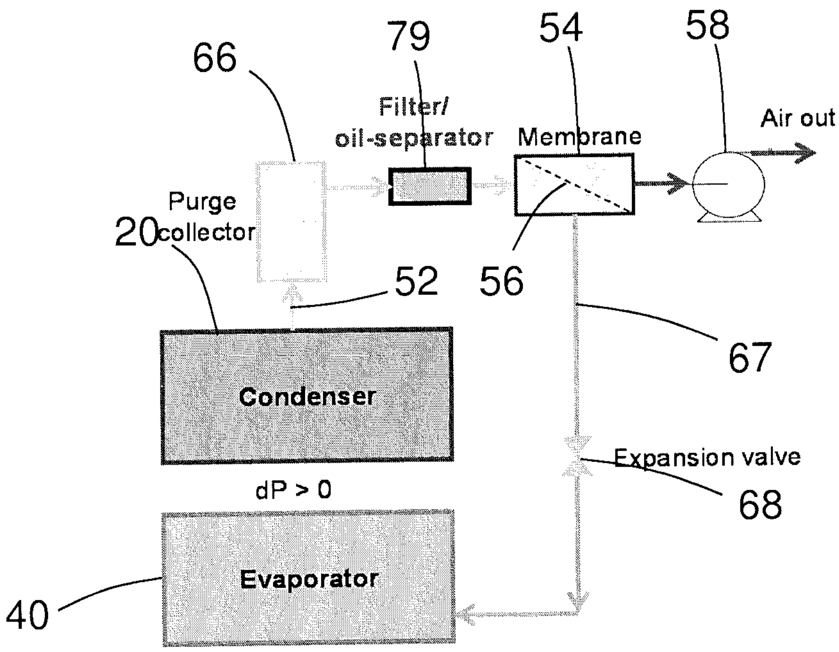
66
79
54
58
Filter/
oil-separator
Membrane
Air out
Purge
collector
20
52
56
67
Condenser
Expansion valve
68
dP > 0
Evaporator
40

FIG. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 18 20 5217

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1

Place of search	Date of completion of the search	Examiner
Munich	4 March 2019	Gasper, Ralf

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