The present disclosure relates to improvements in refrigeration cycles. This disclosure relates to preferred processing of solution from absorber arrangements of absorption refrigeration cycles, to separate out refrigerant liquid. Examples are provided. A variety of equipment configurations, techniques, and processes are disclosed, as examples.
FIG. 7

2e^- + 2H_2O → H_2 + 2OH^-  

1/2 O_2 + 2e^- → H_2O → 2H^+  

Cathode (-)  

Anode (+)
ABSORPTION REFRIGERATION CYCLES; APPARATUS; AND, METHODS
CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application includes, with edits, the disclosure of U.S. provisional application 61/280,105, filed Oct. 30, 2009. The complete disclosure of U.S. provisional application 61/280,105 is incorporated herein by reference. Also, a claim of priority is made to U.S. application 61/280,105 to the extent appropriate.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to refrigeration cycles generally, in which heat is transferred from a heat source to a heat sink. More specifically, the disclosure relates to absorption refrigeration cycles, in which at least one absorber arrangement is used in the refrigeration cycle, for absorbing refrigerant vapor into absorption (strong) solution to generate dilute solution. The techniques particularly relate to processing dilute solution into: (a) strong solution, for example for operation of the absorber arrangement; and, (b) recovered refrigerant liquid, for example for operation of an evaporator, preferably without using a step of vaporizing (boiling) the refrigerant to recover it from the dilute solution, i.e. without conducting a phase change of the refrigerant, for recovery from the dilute solution. General techniques described herein for processing of dilute solution into strong solution (and recovery of refrigerant liquid from the dilute solution) include membrane-based processing, in which a membrane with preferential permeability with respect to one of a solvent or solute is used. An example membrane-based processing by reverse osmosis processing is described. Other processing techniques that can be applied either separately or in conjunction with membrane-based processing include applied electric field processing such as, for example: electrodialysis, electrodemionization, capacitive deionization and membrane capacitive deionization.

BACKGROUND

[0003] Refrigeration cycles are used in a wide variety of applications including: air conditioning; liquid cooling applications; refrigeration; and, heat pumps. These have been applied in a wide variety of industrial and manufacturing applications, as well as environmental cooling and/or heating operations.

[0004] In general, a refrigeration cycle can be used as a cooling device, a heating device, or both. If a relatively low temperature source of heat energy is desired to be kept below ambient conditions as the intended outcome, typically the process will be referenced as a cooling cycle. If a relatively high temperature heat sink is desired to be kept above ambient, the cycle will typically be referenced as a heat pump cycle. Thus, a refrigeration cycle can be used for cooling and/or heating (the later sometimes referred to as heat pumping).

[0005] Many refrigeration cycles are of a type commonly referred to as absorption refrigeration cycles. In general terms, in an absorption cycle, refrigerant is absorbed into a solution, to generate a dilute solution. In a desorber (generator) the refrigerant is released (recovered) from the solution, leaving strong solution behind. The strong solution is directed into an absorber arrangement, in which heat is removed and in which refrigerant, transferred from an evaporator arrangement, is absorbed.

[0006] In general, improvements in refrigerant cycles are desired, for cost effective and efficient energy use. Herein, improvements are described, which at least in part relate to: techniques of generating strong solutions for absorber arrangement operation; and, recovery of refrigerant liquid for use in evaporator arrangement operation of an absorption refrigeration cycle.

SUMMARY

[0007] According to the present disclosure, techniques are provided for modification of practices and equipment concerning refrigeration cycles. Of particular concern, are absorption refrigeration cycles; a general characteristic of which is that within the cycle a vapor (gas) phase refrigerant is absorbed into an absorber solution, to generate a dilute solution; and, refrigerant is recovered from the dilute solution, for use in the refrigeration cycle.

[0008] In general terms, techniques according to the disclosure are applicable to provide for recovery of the refrigerant from the dilute solution, with re-generation of the dilute solution into a concentrated solution (for example for use in an absorber arrangement operation) whereby the refrigerant is efficiently recovered, for example in some applications without vaporizing the refrigerant from the dilute solution and then recondensing; i.e. without a phase change conducted to recover refrigerant from dilute solution. In general, then, certain techniques according to the present disclosure involve absorption refrigeration cycles operated with application of non-vaporizing (i.e. non-phase change) techniques for recovery of refrigerant from dilute solution. A wide variety of such techniques can be applied, including ones now known or later developed. Examples characterized herein for this purpose include membrane-based processing; and/or applied electric field processing.

[0009] In general terms, “membrane-based processing” is solution processing used to regenerate dilute solution into concentrated solution, whereby the refrigerant is recovered, typically without vaporizing the refrigerant from the dilute solution and recondensing, via membrane-based separation. An example membrane-based processing technique described herein as applicable for such a recovery of the refrigerant from the dilute solution, is reverse osmosis processing. By the term “reverse osmosis processing” as used herein, what is meant is processing that involves passing solvent through a reverse osmosis membrane arrangement, to provide: on one (low pressure) side of the reverse osmosis membrane, a relatively purified (reduced solute) solvent; and, on the other (high pressure) side of the membrane, a solution relatively concentrated in solute.

[0010] The reverse osmosis membrane unit system and processing can be conducted in a variety of manners, with the variety of specific equipment configurations. Techniques described in U.S. application Ser. No. 12/455,998, filed Jun. 9, 2009; and, U.S. provisional application 61/131,947, filed Jun. 13, 2008, each of which is incorporated herein by reference, can be applied. Within the present disclosure, some specific example arrangements are characterized.

[0011] Other forms of membrane-based processing that can be applied in overall systems and processing techniques according to the present disclosure include ones in which the membrane is selected for passing of solute.
Other refrigerant recovery techniques usable in accord with the present invention include applied electric field processing. There may also be non-vaporizing, i.e. non-phase change. Herein the term “applied electric field processing” is meant to refer to any solution processing technique in which the solution is passed through a cell or system of cells, across which an electric field is applied. Under the influence of the applied electric field, selected solute migration can occur, with the equipment configured to provide for a net result of a reduced solute solution; and, in many instances, recovery of the solute inclusion into a concentrated solute solution or composition. Examples of applied electric field processing usable with techniques according to the present disclosure include: electrodialysis; electrodereionization; capacitive deionization; and, membrane capacitive deionization, although any variety of techniques now known or later developed can be used.

Various types of non-vaporizing (non-phase change) solution processing techniques for recovery of refrigerant and generation of concentrated solution can be used independently or together, with systems, arrangements and techniques according to the present disclosure. Multiple stages or cascading effects can be used, to accomplish relatively pure solvent (refrigerant) recovery and/or generation of the relatively strong concentrated solute solution.

It is noted that in some systems and processes according to the present disclosure, solution processing can be conducted with a number of different specific types of non-vaporizing (i.e. non-phase change) solution processing, in the same system. For example, reverse osmosis techniques can be applied in the same system in which applied electric field processing is also used. In accord with terminology used herein, such a system can be characterized as comprising a “reverse osmosis membrane (unit) system” or by similar terms; or, alternatively, as a “applied electric field processing (unit) system” or by similar terms, or by both terms.

It is also noted that many of the techniques described herein can be applied, to advantage, in processing or processing systems in which is also same vaporization of refrigerant during recovery.

There is no requirement that all specific equipment configurations, materials, and processing steps characterized herein, be used in all practices in accord with the general principles of the present disclosure. Variations are possible, as will be understood from the following descriptions.

FIG. 4 is a schematic depiction of a first alternate absorption refrigeration cycle, to the one of FIG. 3, using techniques according to the present disclosure.

FIG. 5 is a schematic depiction of a second alternate absorption refrigeration cycle using techniques according to the present disclosure.

FIG. 6 is a schematic depiction of a third alternate absorption refrigeration cycle using techniques according to the present disclosure.

FIG. 7 is a schematic depiction of an example of applied electric field processing system.

DETAILED DESCRIPTION

I. Further Regarding Prior Art Refrigeration Cycles

A. Prior Art Vapor Compression Cycles—Generally

In FIG. 1, a prior art vapor basic compression cycle is depicted, schematically, at 1. Referring to FIG. 1, at 3 a refrigerant compressor is depicted schematically. In general, the refrigerant compressor 3 is operated to compress refrigerant (in a vapor or gas phase) transferred thereto via conduit or line 4, to generate a compressed refrigerant (vapor or gas) in conduit or line 5. Conduit or line 4 will generally be referred to as a high pressure refrigerant vapor (or gas) conduit or line; and, line 5 as a high pressure refrigerant vapor (or gas) conduit or line. In a typical process, heat will have been imparted to the refrigerant, during the process of compression in the compressor 3, so the refrigerant vapor (gas) in conduit or line 5 will typically be relatively hot by comparison to the refrigerant vapor (or gas) in conduit or line 4. Also, the increased pressure allows for condensing of refrigerant vapor at an increased temperature (and vice versa on the low pressure side of the system).

It is noted that herein, in connection with refrigeration cycles, phase changes of refrigerant between a gas phase and a liquid phase are characterized. In general, the terms “vapor” and/or “vapor phase” are used herein interchangeably with the terms “gas” and/or “gas phase,” to characterize the refrigerant when it is in the gas or vapor phase. Similarly, the terms “boiling” and “vaporizing” are meant to be used interchangeably. The terms “conduit” and “line” are also meant to be used interchangeably.

Relatively high pressure refrigerant (vapor or gas) from line 5 is directed to a condenser arrangement at 7. In the condenser arrangement or system 7, the refrigerant (vapor or gas) is condensed to a pressurized refrigerant liquid. The pressurized refrigerant liquid is shown leaving the condenser arrangement at line 8. During operation of the condenser arrangement 7, heat (energy) is removed from the refrigerant (vapor or gas) and is transferred out of the system. In general, this heat transfer out is indicated by arrows 9. It is noted that the heat can be expelled as heat to the environment, for example in operation of a typical air conditioner, or it can be captured in another material, and be applied in a selected manner. In FIG. 1, line 9 is meant to indicate introduction of a heat sink to the condenser arrangement 7, for example air or liquid, to which heat, given off during the condensation of the refrigerant, is transferred. Of course, the heat sink can be the environment.

The pressurized refrigerant liquid of line 8, from the condenser 7, is shown in the refrigeration cycle 1, as directed into an expansion system or device 10, in which the pressure is reduced. The reduced pressure refrigerant liquid from the expansion (or pressure reduction) system 10 is shown then
directed through line 12 into evaporator arrangement or system 13 via a distribution system or other arrangement.

In the evaporator arrangement 13, heat is transferred to the refrigerant liquid, vaporizing (evaporating) some (or all) of the refrigerant liquid. The vaporized refrigerant is shown leaving the evaporator arrangement 13 at line 15, which via line 4 is directed back into the refrigerant compressor 3, for compression.

The heat transfer which occurs in the evaporator system 13 cools the material from which the heat is transferred. For example, if the heat transferred into the evaporator 13 is from a hot air source, the result will be a cooling of the air, which is typical of an air conditioning cycle. Of course, other relatively hot materials (for example liquid or gas) can be directed into the evaporator 13, for transfer of heat to the refrigerant with the result being a cooled liquid or gas (and a vaporized refrigerant). Still referring to FIG. 1, the hot material transferred into the evaporator system 13, is shown generally at lines 16. Removal of the cooled material is shown at 17.

A wide variety of equipment configurations, conduit configurations, pump configurations, etc. can be used. No specific combination of equipment is meant to be indicated, other than for providing general operation.

In the general terms used herein, the refrigeration cycle 1, for example, could be an air conditioning cycle, if the system is operated to provide cool air to an environment from the evaporator 13 via output 17. The refrigeration cycle 1 would be characterized as a heat pump, since it is operated to provide heated air to an environment, via the condenser 7 and output 9.

A typical present-day, state-of-the-art water cooled vapor compressor refrigeration cycle, operating at the Air Conditioning, Heating and Refrigeration Institute, AHRI standard full load conditions of 85°F (29.4°C) condenser water entering temperature and 44°F (6.7°C), leaving chilled water temperature, is capable of producing 1 ton (12,000 Btu/hr), or 3.517 kW) of cooling capacity for between 0.58 and 0.62 kW/ton of energy input (0.165 to 0.171 kW of input per kW of output). Reference to 85°F (29.4°C) condenser water, would be the temperature of the condenser water for operation of condenser arrangement 7; and, the reference to 44°F (6.7°C) chilled water temperature, is referring to cooling output from evaporator arrangement 13, shown at line 17 in a typical water chilling application.

Above it was noted that some or all of the refrigerant liquid may be vaporized in the evaporator arrangement 13. There is no specific requirement that all of the refrigerant liquid be vaporized in the evaporator arrangement. The extent, to which vaporization occurs in the evaporator arrangement, will typically turn on the type of evaporator arrangement used.

In the refrigeration industry today there are three commonly used evaporator configurations. These are: "flooded," "Direct Expansion (DX)," and "liquid overhead." Under normal operating circumstances, heat is transferred to the evaporator heat exchanger; this heat transforming the refrigerant through a phase change from a liquid into a gaseous state. In the flooded and direct expansion configurations liquid is fed into the evaporator and evaporated (gaseous) refrigerant is removed from the evaporator system. In these configurations the mass of liquid added to the evaporator in steady state steady flow conditions is equal to the mass of gaseous refrigerant removed from the evaporator. The flooded and direct expansion system these systems are designed with the intent of only removing a gaseous refrigerant from the evaporator arrangement.

A liquid overfeed evaporator arrangement is designed such that a liquid refrigerant is fed into the evaporator and a mixture of both: a) un-evaporated refrigerant liquid; and, b) evaporated gaseous refrigerant, is removed from the evaporator. Thus, in the case of the liquid overfeed arrangement the entirety of the refrigerant entering the evaporator is not evaporated prior to leaving the evaporator.

In a flooded evaporator arrangement, a separate vessel is typically provided which serves to gravity feed liquid refrigerant into the coil while vaporized gaseous refrigerant is bubbled out of the evaporator.

Herein, in both the prior art systems and the improved systems characterized, the evaporator arrangement depicted may be of the type which completely vaporizes refrigerant liquid, or which only partially vaporizes the refrigerant liquid. Either can be used with techniques as described herein.

B. Prior Art Absorption Refrigeration Cycles—Generally

Attention is now directed to FIG. 2, in which a prior art basic absorption refrigeration cycle is indicated generally at 30. Referring to FIG. 2, refrigerant (gas or vapor) is shown at line 31 directed into condenser arrangement 32. The condenser arrangement 32 of system 30 can be analogous to, and be operated analogously to, condenser arrangement 7, FIG. 1. Heat output from the condenser 32 is shown at lines 33, and comprises heat rejection to the environment or captured in a sink for use. A heat sink (gas or liquid) input for this is shown at 33x.

Condensed refrigerant is shown leaving the condenser 32 via line 35. Line 35 is typically pressurized, as will be understood from the remaining parts of this description. At 36, the pressurized, condensed, refrigerant (liquid) of line 35 is depicted passed through an expansion or pressure reduction device to reduce pressure, with line 37 comprising a reduced pressure refrigerant line or distribution device directed into evaporator arrangement or system 39. In the evaporator arrangement or system 39, some (or all) of the refrigerant is evaporated, with the resulting gas (vapor) phase refrigerant shown removed from evaporator arrangement or system 39 at line 40. Evaporator arrangement or system 39 can be analogous to evaporator 13, FIG. 1, with heat transfer (input) into the evaporator 39 shown at lines 41. Again, for example, the heat input at lines 41 can be from hot air, for example if the absorption cycle 30 is operated as an air conditioner. It can also be a transfer of heat from another heat source. The cooled material (air, water, etc.) from evaporator system 39 is shown at line 42.

The low pressure refrigerant vapor of line 40 is shown being directed into absorber arrangement or system 45. Within the absorber arrangement or system 45, the refrigerant is absorbed into solution indicated generally in sump 46. The solution is typically characterized as an "absorption solution," "absorber solution" or by related terms and can comprise a variety of materials. Typically, the absorber solution, before absorption of the refrigerant therein, is a solute/solvent solution typically referred to as "strong," i.e. relatively concentrated in solute. By the term "relatively" concentrated, in this context, reference is meant by comparison to the refrigerant absorption. In general terms, the solute provides for
relatively low solvent vapor pressure to the solution, in this instance by comparison to the solvent without the solute therein.

[0043] The absorber solution, once diluted by the absorbed refrigerant, as shown at sump 46, is sometimes referenced as "dilute solution." The dilute solution is shown leaving the absorber at line 48. It is directed into pump 50, by which it is pressurized, resulting in a pressurized dilute solution line being indicated generally at 51. The pressurized dilute solution line 51 is directed into a desorber (or generator) arrangement or system 55. In general, the desorber arrangement 55 is operated with a thermal (i.e., energy) input indicated generally at 56, which will serve to boil off the refrigerant, generating a pressurized refrigerant vapor phase in line 58; and, regenerating the dilute solution into a strong solution. The refrigerant vapor phase generated in the desorber 55 is shown directed to line 31, a refrigerant vapor inlet line to the condenser system 32.

[0044] In general, then, a characteristic of an absorption cycle 30 of the prior art characterized herein in connection with FIG. 2, is that in an absorber arrangement refrigerant is absorbed into an absorption solution, to create a dilute solution; and, the refrigerant is recovered from the dilute solution by vaporizing the refrigerant out of solution.

[0045] Within the desorber (generator) system 55, as a result of removal of refrigerant gas (vapor), strong solution or strong absorbent solution is re-generated, shown being removed from desorber system 55 at line 59. This solution is depicted directed from through a pressure reducer 60, and into a reduced pressure strong solution line 61, which typically includes strong (i.e., concentrated) solution or absorber solution. This line is directed into absorber arrangement or system 45.

[0046] Referring to the example absorber arrangement 45 depicted, the strong solution from line 61 is shown directed therein via optional sprayer arrangement 62, which will distribute the strong solution through the absorber arrangement 45. The strong solution is also shown absorbing the refrigerant, to generate dilute solution in sump 46. As the refrigerant vapor is absorbed into the absorber solution, energy will be released. This energy will tend to produce heating of the absorber solution. To keep the vapor pressure of the absorber solution low it is desirable to keep the absorber solution temperature low. To do this, heat is typically removed from the absorber solution. One way to accomplish this heat removal is to transfer this heat into an absorber heat transfer loop such as is shown at 65. Referring to FIG. 2, the example absorber arrangement 45 depicted includes therein optional packing 45a to facilitate heat transfer, and refrigerant absorption, by increasing surface area.

[0047] The absorber heat transfer loop 65 is shown transferring heated material via line 66, for example heat from absorber arrangement 45 having been absorbed by another gas or liquid (heat sink) into a heat transfer arrangement 70. Heat removed via the heat transfer arrangement 70 is shown at lines 71. The (relatively) cooled circulation fluid is shown leaving the heat transfer unit 70 via line 72, by which it is directed back into the absorber 45 via heat transfer loop 65.

[0048] Prior art absorption cycles are predominately thermally driven (also known as heat driven) cycles with only a relatively small amount (in relation to the amount of thermal energy required) of mechanical energy need to operate the pumping components of the cycle. For the depicted cycle 30, the absorption cycle thermal energy input at 50 can be derived from a variety of sources. Common examples include natural gas, fuel oil, steam or hot water. Absorption refrigeration cycles are typically rated in terms of their Coefficient Of Performance, or COP for short, where COP is the ratio of the cooling energy produced divided by the input energy required to drive the cycle. In typical water chilling applications, a single stage water cooled absorption refrigerant cycle operating an AHRI standard full load conditions is capable of producing one ton (3.517 kW) of cooling capacity for approximately 10,000-12,000 Btu/hr of energy input rate. This equates to a COP range of 0.83 to 1.0.

[0049] Still referring to FIG. 2, attention is directed to optional heat exchanger 73. Heat exchanger 73 is configured and positioned to transfer some of the heat from line 55 into line 51. Such a heat exchanger, sometimes characterized as a "GAX" or generator absorber arrangement, can be used in association with a generator or desorber 55.

[0050] It is noted that both of the cycles 1 and 30, are depicted schematically. A wide variety of equipment configurations are possible, for the various evaporator arrangements, condenser arrangements, absorber arrangements, desorber arrangements, heat transfer arrangements as well as for the lines, pumps, compressors, and expansion or pressure reduction devices. There is not meant to be any specific mechanical configuration for the components, or operation of them, implied by the descriptions.

C. Typical Traditional Approaches to Improving Refrigeration Cycles

[0051] Since their inception, the basic cycles described above (vapor compression and absorption) have been improved upon in terms of operational efficiency through various alterations or enhancements to the basic cycles. Enhancements such as in development of various heat recovery mechanisms, multi-staging, intercoolers, and overall improvements in efficiency of individual components of the cycles have been made. However, the fundamental principles of the cycles have remained unchanged to a great extent. At present, these cycles are typically considered the most cost-effective and efficient refrigeration cycles available. While other refrigeration cycles exist, for example thermal acoustic and thermal electric, vapor compression cycles and absorption cycles are, at present, the most commonly used refrigeration cycles.

II. Improved Absorption Cycles—Generally

[0052] In a typical, traditional, absorption cycle, FIG. 2, separation of the refrigerant liquid out of the absorption solution (see desorber 55, FIG. 2) is a distillation or boiling process. That is, sufficient energy is put in to vaporize (phase change) refrigerant liquid in the dilute solution to a gaseous state, to separate it from the dilute solution; with the remaining solution after refrigerant desorption being increased in solute concentration (to a concentrated or strong solution). In general, substantial energy input to a desorber or generator is needed, for separation of the refrigerant (by boiling i.e. phase change) from the dilute solution to occur.

[0053] According to the present disclosure, an alternative is provided: (a) to using thermal energy input to a desorber system to produce a phase change of the refrigerant for concentrating the absorbent solution from a dilute (weak) solution to a more concentrated solution; and, (b) to separate the refrigerant from the dilute solution as a vapor phase. In some
examples, reverse osmosis processing is applied, which allows avoidance of a relatively energy inefficient step of converting the refrigerant to the gas phase during refrigerant recovery from the dilute solution.

[0054] In more general terms, non-vaporizing solution processing is used with assemblies and systems and techniques according to the present disclosure for processing of solution in the alternative to installation of vaporizing processes. The terms “non-vaporizing solution processing,” “non-phase change solution processing” and variants thereof as used herein, are meant to refer to any solution processing technique, now known or later developed, in which refrigerant is recovered from dilute solution, without a phase change in the refrigerant occurring. This also generally leads to concentrated solution regeneration.

[0055] Examples of currently available and usable non-vaporizing solution processing techniques (i.e. non-phase change solution processing) usable with systems, arrangements and techniques according to the present disclosure, include membrane-based processing and applied electric field processing. These techniques, characterized more specifically below, can be applied independently or together in a system to accomplish system processing. Also, each term is not meant to be exclusive of the other.

[0056] As used herein in this context, the terms “membrane-based processing,” “membrane-based solution processing” and variants thereof, are meant to refer to processing in which a membrane or membrane arrangement is provided, with preferential transfer of material across the membrane used facilitate solution processing. Reverse osmosis processing is an example of membrane-based processing, in which a reverse osmosis membrane arrangement is provided, so that the solvent from a solution on one side will tend to pass through the membrane in a manner increasing concentration in solute on one side and providing for increased amounts of reduced solute solvent on the other.

[0057] In general, the term “applied electric field processing” and variants thereof, as used herein, is meant to refer to forms of non-vaporizing solution processing (i.e. non-phase change solution processing) in which the electric field is applied to the solution in a manner facilitating prefered migration of solute or selected solute materials. This can be used, for example to drive solute materials out of the solution, generating a reduced solute solution. This technique can also be used to recover the solute, to facilitate generation of a concentrated solute solution. Examples of applied electric field processing referenced specifically herein, include electrodialysis processing, electrodeionization processing, capacitive deionization processing and membrane capacitive deionization.

[0058] In some processes, more than one type of a non-vaporizing processing can be applied to accomplish desired solution processing. For example, it may be desirable to process dilute solution from an absorption refrigeration cycle, via the applied electric field processing, when the solution is most concentrated in solute. Then, after initial applied electric field processing, one can use reverse osmosis processing techniques to further process the solution, into purified solvent. A use for this type of processing can be when the solute concentration is so high that an undesirable level of pressure, or number of stages, is needed to be applied to the solution to accomplish effective reverse osmosis processing.

[0059] When the system is one in which both “membrane-based processing” and “applied electric field processing” is used, the system or process can be characterized as comprising “membrane-based processing” and/or as comprising “applied electric field processing” and by variants thereof.

[0060] In general, because a non-vaporizing processing is used in the present disclosure to recondense the absorption solution, the energy and process of boiling off a refrigerant to get it out of the absorbent liquid is no longer required. In addition, because the separation of the refrigerant from the absorption solution is not accomplished via a boiling off process, with the presently described techniques, a condenser arrangement is not required to condense the refrigerant vapor and reject energy from this portion of the cycle.

[0061] As an example, pressurizing and conveying a liquid, as is the case in the example presently described systems when reverse osmosis processing is the membrane-based processing used, is less energy intensive that pressurizing (compressing) and conveying a gas, as would be used in a vapor compression or refrigeration cycle. This is in part because liquids are less compressible than gases, and therefore less work (energy) is needed to raise the pressure of a liquid than would be required for an equivalent mass of the same gas. Indeed, in a gas compression process, much of the work required to compress the gas is converted into heat rather than into the increased energy state of the compressed gas. The heat of compression is a byproduct of the overall gas compression process, and is commonly viewed as an expression of the inefficiencies of the process. For example, in a standard zero psig (1 bar) to 100 psig (7.9 bar) air compressor, approximately 80% of the energy input into the compressor ultimately gets lost as heat, rather than producing actual compressed air.

[0062] A typical operating concentration of absorbent solutions required to effectively operate a refrigeration cooling cycle such as the absorption cycle of FIG. 2, with standard AHRI full load conditions, would present calculated (or predicted) osmotic pressures on the order of 8,000 to 12,000 psig (552 to 827 bar), depending on the solution used, the solution operating temperature, and membrane effectiveness. Currently available reverse osmosis membrane units on the market are typically capable of operation only up to a maximum operating pressure of about 690 psig (48.6 bar), i.e. on the order of a magnitude less pressure than would be required for an absorption osmosis refrigeration cycle. Therefore, with currently available reverse osmosis membrane technology, a cascading type reverse osmosis membrane unit system, for example as described in U.S. patent application Ser. No. 12/455,998 filed Jun. 9, 2009; and, in U.S. provisional application 60/131,947, filed Jun. 13, 2008, will often be used. Examples are described and depicted herein.

[0063] Again, and as will be discussed further below, alternate non-vaporizing solution processing as an alternate to, or in addition to, reverse osmosis processing, can be used. Here, advantages will result when the specific non-vaporizing solution processing technique is energy efficient, relative to the techniques that involve vaporization, etc. For example, when the non-vaporizing processing is applied electric field processing, efficiencies will result when the amount of applied electric field (and energy associated with generation and maintenance thereof) is less than the alternate system demands in the presence of a vaporization, etc.

[0064] In general, an absorption cycle improved according to the present disclosure, if optimally configured, can be substantially more efficient than a vapor compression refrigeration cycle.
eration cycle or a traditional absorption refrigeration cycle. This will be apparent from the following descriptions.

III. An Example Improved Absorption Cycle, FIG. 3

[0065] Attention is now directed to FIG. 3, in which an improved absorption refrigeration cycle is indicated generally at 80. The improved absorption refrigeration cycle 80 may be referred to herein as an "absorption osmosis refrigeration cycle" or by similar terms, when the system is configured to include a reverse osmosis membrane unit system, and a reverse osmosis processing step, in the cycle.

[0066] Referring to FIG. 3, the absorption cycle 80 is similar to absorption cycle 30, FIG. 2, except for the absence of: the desorber (generator) 55; and, the condenser 32. Instead, conversion of the dilute solution line from the absorber arrangement into: (a) a strong solution line for use in an absorber arrangement loop; and, (b) a refrigerant liquid line for use in an evaporator arrangement, is provided by non-vaporizing solution processing; for example a reverse osmosis processing, using a reverse osmosis (membrane) unit system. In FIG. 3, a non-vaporizing solution processing unit system for this purpose is indicated generally (and schematically) at 82. The non-vaporizing solution processing system 82 can, for example, be a reverse osmosis processing unit system as discussed below, or an alternate system, as also discussed below.

[0067] In general terms, a characteristic of an improved absorption refrigeration cycle in accord with the present disclosure, is that a desorber (generator) operated to process the dilute solution into: (a) vapor phase refrigerant line; and, (b) a strong solution line, that is operated by conducting a phase change on the refrigerant (typically liquid to gas) to affect the separation is not used. Rather, the dilute solution is processed into: (a) a concentrated or strong solution; and, (b) liquid phase refrigerant, by using non-vaporizing solution processing techniques, such as membrane-based techniques (for example reverse osmosis) and/or applied electric field techniques (such as electrodialysis; electrodersonization; capacitive deionization; and, membrane capacitive deionization). These techniques do not involve a phase change for the refrigerant, in connection with the solution processing (refrigerant recovery and solution re-concentration).

[0068] Referring to FIG. 3, dilute solution (containing refrigerant) from an absorber arrangement 83 is shown in line 84 being directed into the non-vaporizing solution processing unit system 82. Line 84, in general terms, comprises a solution to be processed by the non-vaporizing solution processing unit system 82. At line 88, a concentrated solution out from the non-vaporizing solution processing unit system 82 is shown. At line 86, a purified solvent line (liquid refrigerant line) out from the non-vaporizing processing unit system 82 is shown. Because the solvent comprises the refrigerant, then, line 86 can be characterized as a refrigerant liquid line 87. When the concentrated solution line out 85 comprises strong solution for the absorber arrangement 83, line 85 can be referred to as the strong solution line 88.

[0069] It is noted that in parent U.S. provisional application 61/280,105, the non-vaporizing processing unit system 82 was specifically referred to as a "reverse osmosis membrane unit system", since a specific example non-vaporizing solution processing technique that was described therein, to avoid vaporization processing, was reverse osmosis unit processing, generally in accord with U.S. application Ser. No. 12/455,998.

[0070] In other aspects, cycle 80 is analogous to cycle 30. Thus, refrigerant liquid 87 is directed into (a first) evaporator arrangement 90, which can be analogous to evaporator 39. Heat transfer to the refrigerant liquid in the evaporator arrangement 90 is provided by heat input at lines 91, which for example can be heat provided by a hot gas (for example air) or a liquid. This will provide a cooling effect on the air or liquid involved, shown leaving the evaporator arrangement 90 at 92. At line 95 refrigerant, at least a portion of which is now refrigerant gas (vapor), is shown removed from the evaporator arrangement 90 and directed to (a first) absorber arrangement 83. At 96, dilute solution within the absorber arrangement 83 is shown, resulting from absorbing the refrigerant vapor into liquid of a strong solution (absorption solution), in the example from line 88 fed into the absorber arrangement 83. This generates the dilute solution of line 84.

[0071] Also, analogous to the cycle 30, FIG. 2, strong solution 88, FIG. 3 is shown directed into the absorber arrangement 83, in the example via optional spray arrangement 97. Heat transfer from the absorption solution occurs, within the absorber arrangement 83, into absorber cooling loop 99. Absorption solution, diluted with refrigerant, is shown in sump 96. Within absorber arrangement 83 is depicted optional packing 83x; to increase surface area for absorption.

[0072] Absorber heat transfer loop 99 is shown transferring fluid from absorber arrangement 83 to heat recovery or transfer unit 100. Heat (energy) recovered or rejected from the unit 100 is shown taken off at lines 101. While this is a heat rejection from the system 80, it can be captured and used if desired. At line 103 fluid from the absorber heat transfer loop 99 is shown directed back into the absorber arrangement 83, as a sink for heat transfer from the absorbing solution in the absorber arrangement 83.

[0073] Again, then, in general system 80 is analogous to system 30, except for removal of: a desorber (generator) 55 that separates refrigerant by phase change; a condenser 32 that converts the vapor phase refrigerant from the desorber to a liquid phase; and, the use of the non-vaporizing solution processing unit system 82, for example configured to include: a membrane-based processing unit system such as reverse osmosis (membrane) unit system, another type of non-vaporizing solution processing system (such as applied electric field processing unit system), or both.

[0074] A variety of configurations of equipment can be used for the non-vaporizing processing unit system 82. For example, when the system 82 is a reverse osmosis (membrane) unit system, if available, a single reverse osmosis membrane unit could be used for the reverse osmosis membrane unit system 82, with: (a) solution to be processed directed in via line 84; (b) selected liquid (refrigerant) transferred across the reverse osmosis membrane arrangement and thus separated, shown removed via line 86; and, (c) concentrated high pressure side outlet (concentrated or strong solution) shown removed via line 85. However, in general, for efficient operation of an absorbent refrigerant cycle, with one reverse osmosis unit, a sufficiently high pressure would be required (across the membrane arrangement) that typical conventionally (currently) available reverse osmosis membranes would not be adequate. As a result, when currently available membrane technology and techniques, for reverse osmosis processing is used in membrane-based processing unit system 82, it will typically comprise a cascading reverse osmosis membrane unit system, applying principles in general accord with those described in U.S. patent application Ser. No.
reverse osmosis membrane technology, if the components included within the housing are appropriately configured.

[0081] Referring to FIG. 3A, the example system 82 depicted is generally as follows: dilute solution input at 84, is directed through reverse osmosis (RO) pump 100 to provide a pressurized solution in liquid line 101. At A is depicted a reverse osmosis unit, comprising a reverse osmosis membrane arrangement 105, with a high pressure side 105x and low pressure side 105y. The solution 84, pressurized by pump 100 is shown directed into reverse osmosis unit A via low pressure side inlet line 106. Reverse osmosis unit A has a low pressure side outlet indicated generally at 107. Within the reverse osmosis unit 105, a solution directed into high pressure side inlet 108 is concentrated by passage of solvent across the membrane arrangement 105 into side 105y. At 109, a high pressure side concentrate outlet line is shown from unit 105. At 110 a pressure reduction device is shown so that the pressure of the concentrated solution outlet can be reduced; concentrated solution out from system 82, being shown via line 85. The pressure reduction device 110 can be of any number of configurations and can be used to generate mechanical or electrical power.

[0082] Low pressure side outlet line 107 from unit A is shown directed into reverse osmosis unit B, which comprises a reverse osmosis membrane arrangement 115 defining a high pressure side 115x and a low pressure side 115y. Low pressure side inlet line 116 for unit B comprises a low pressure side outlet from unit A via line 107. It is noted that at joint 118, the liquid in line 107 is split, with a portion directed via line 119 into reverse osmosis pump 120, to create a pressurized line 121 directed to joint 122.

[0083] At 124 a low pressure side outlet line from reverse osmosis membrane unit B is shown. This is directed as a low pressure side inlet line to reverse osmosis unit C.

[0084] Reverse osmosis unit C comprises a reverse osmosis membrane arrangement 130 with a high pressure side 130x and a low pressure side 130y. Reverse osmosis unit C has: a high pressure side liquid inlet line 131; a high pressure side liquid outlet line 132; a low pressure side liquid inlet line 134, and, a low pressure side liquid outlet line 133.

[0085] Low pressure side outlet flow from line 133 is directed to joint 135 where it is split into: (a) a line 136, directed to reverse osmosis unit D as a low pressure side inlet; and, (b) line 137, directed to reverse osmosis unit pump 138 and into pressurized line 139. Flow in line 139 is directed to joint 196, referenced below.

[0086] Reverse osmosis unit D comprises reverse osmosis membrane arrangement 140 with a high pressure side 140x and a low pressure side 140y. The unit D has: a low pressure side outlet line 141; a high pressure side inlet line 142; and, a high pressure side outlet line 143, in addition to the low pressure side inlet line 136.

[0087] The low pressure side outlet line 141 from reverse osmosis unit D (which represents a reduced solute solvent or purified solvent line from unit D) is shown directed to reverse osmosis unit E. Reverse osmosis unit E comprises a reverse osmosis membrane arrangement 150 defining a high pressure side 150x and a low pressure side 150y. The unit E has: a low pressure side inlet line 151, which receives liquid from line 141; a low pressure side outlet line 152; a high pressure side inlet line 153; and, a high pressure side outlet line 154. In general, line 152 comprises a reduced solute solvent or purified solvent outlet line from unit E. Line 152 is directed to
joint 156, where it is split into line 157 and line 158. Line 157 is directed as a low pressure side inlet line to reverse osmosis unit F.

[0088] Reverse osmosis unit F comprises a reverse osmosis membrane arrangement 160 having a high pressure side 160r and a low pressure side 160l. In addition to low pressure side inlet line 157, reverse osmosis unit F is operated with: a low pressure side outlet line 161; a high pressure side inlet line 162, and a high pressure side outlet line 163. Low pressure side outlet line 161 can be viewed as a reduced solute solvent or purified solvent outlet line from reverse osmosis unit F. This line 161 is directed, in the example shown, as a low pressure side inlet line 166 for reverse osmosis unit G.

[0089] Reverse osmosis unit G comprises a reverse osmosis membrane arrangement 170 having a high pressure side 170r and a low pressure side 170l. Reverse osmosis unit G is operated with: low pressure side inlet line 166; low pressure side outlet line 171; high pressure side inlet line 172; and, high pressure side outlet line 173.

[0090] The low pressure side outlet line 171 generally represents a reduced solute solvent or purified solvent line from reverse osmosis unit G. As shown, line 171 is directed via reverse osmosis pump 175 into line 176, a high pressure side inlet line for reverse osmosis unit H.

[0091] Reverse osmosis unit H has a reverse osmosis membrane arrangement 180 defining a high pressure side 180r and a low pressure side 180l. Reverse osmosis unit H can be viewed as a final “polishing” reverse osmosis unit system, for purifying the solute (refrigerant) of system 82. A low pressure side outlet line from reverse osmosis unit H is shown at 181. When used in connection with the overall system of FIG. 3, line 181 reflects a purified refrigerant liquid line, to be directed to the evaporator arrangement 90 via line 86, FIG. 3.

[0092] Reverse osmosis unit H, FIG. 3A, also has a high pressure side outlet line indicated at 182. Line 182 carries solute (concentrated as a result of the operation of the reverse osmosis unit H) in high pressure side solvent. In the system of FIG. 3A, it is shown directed through pressure reducer 183 and into high pressure side inlet line 172 for operation of reverse osmosis unit G. Within reverse osmosis unit G, the high pressure side liquid is further concentrated in the solute, as a result of the movement of solvent across membrane 170, with line 173 being an increased concentration line in solute relative to the concentration of solute in line 172. At joint 190, a portion of liquid from line 152 (directed into line 158, from joint 156) is shown after pressurization of reverse osmosis unit pump 191 being directed via line 192 to join with the liquid in line 173. This mixed liquid solution is directed as a high pressure side inlet via line 162 into reverse osmosis unit F. At 163, the high pressure side outlet from reverse osmosis unit F, which is concentrated in solute relative the concentration in line 162, is shown directed into the high pressure side inlet 153 for reverse osmosis unit E. At 154, a high pressure side outlet, which is concentrated in solute relative to line 153, is shown directed to joint 196. At joint 196, the liquid from line 154 is joined with liquid from line 139 and is directed to high pressure side inlet line 142 for reverse osmosis unit D. At line 143 a high pressure side concentrate outlet line from reverse osmosis unit D is shown, concentrated in solute relative to line 142, being taken off unit D and being directed as a high pressure side inlet line 131 to reverse osmosis unit C.

[0093] At line 132, high pressure side concentrate (concentrated in solute relative to line 131) is shown being removed from reverse osmosis unit C and directed to joint 122, where it is joined with liquid in line 121 and directed to high pressure side inlet line 198 to reverse osmosis unit B. At 199, a high pressure side outlet line from reverse osmosis unit B is shown. High pressure side outlet line 199 would be concentrated in solute, relative to the concentration in inlet 198. Line 199 is shown in FIG. 3A directed to reverse osmosis pump 200 and then into high pressure side inlet line 108 for reverse osmosis unit A. High pressure side outlet line 109, which would be concentrated in solute relative to line 108, is then shown directed to pressure reducer 110 and taken from non-vaporizing processing unit system 82 as a concentrated solution in solute, via line 85. This would, then, comprise strong solution in line 85, FIG. 3, for operation of the absorber arrangement 83.

[0094] In general, then, when the non-vaporizing solution processing unit system 82 uses reverse osmosis processing, the system 82 operates to take a solution in line 84 and process it into two outlet solutions: (a) a concentrated solute solution, line 85; and, (b) a reduced solute, relatively purified solvent, line 86.

[0095] In the overall context of the absorption refrigeration cycle of FIG. 3, dilute solution at line 84 is processed into a recovered refrigerant liquid line 86 and a concentrated or strong solution line 85, without the need for a step involving either: a desorber (generator) 55 to convert refrigerant to a vapor (gas) phase for separation, FIG. 2, or a condenser 32, FIG. 2, to convert the refrigerant back to a liquid phase, for direction to the evaporator arrangement 90, of FIG. 3.

[0096] In general terms, a reverse osmosis membrane unit system, as depicted in FIG. 3A, can be characterized as including a first, final, dilute solvent outlet-generating reverse osmosis unit (unit H); a first, final, concentrate outlet-generating reverse osmosis unit (unit A); and, an intermediate reverse osmosis (membrane) (unit) system comprising at least one reverse osmosis unit, in this instance comprising units B, C, D, E, F and G. Further, unit B can be characterized as a final, concentrate flow direction (or first solvent or dilute solvent flow direction) reverse osmosis unit of the intermediate reverse osmosis (membrane) (unit) system; and, unit G can be characterized as a first, concentrate flow direction or final solvent (or dilute solvent) flow direction reverse osmosis (membrane) unit of the intermediate reverse osmosis (membrane) (unit) system.

[0097] Further, although not required in all applications of the techniques described herein, the reverse osmosis system, FIG. 3A can be characterized as a process conducted such that:

[0098] (a) concentrate from the first, final, solvent outlet-generating reverse osmosis unit is directed into the intermediate reverse osmosis membrane unit system, as part of a feed stream thereto;

[0099] (b) reduced-solute solvent from the intermediate reverse osmosis membrane unit system is directed to the first, final, solvent outlet-generating reverse osmosis unit as part of an inlet feed stream thereto;

[0100] (c) concentrate from the intermediate reverse osmosis membrane unit system is directed into the first, final, concentrate outlet-generating reverse osmosis unit as part of an inlet feed stream thereto;

[0101] (d) each reverse osmosis unit in the intermediate reverse osmosis membrane unit system is conducted with both a high pressure side inlet feed and a low pressure inlet feed;
(e) Each reverse osmosis unit in the intermediate reverse osmosis membrane unit system provides a high pressure concentrate outlet and a low pressure side outlet; and,

(f) The dilute solution to be processed is directed into at least one of: the first, final, solvent outlet-generating reverse osmosis unit; the intermediate reverse osmosis membrane unit; and, the first, final, concentrate outlet-generating reverse osmosis membrane unit.

Of course a wide variety of equipment configurations can be used for the reverse osmosis processing and the RO unit system. The examples depicted, are meant to indicate generally the principle that the processing of a dilute solution, from an absorber arrangement in a absorption refrigeration cycle, can be conducted by reverse osmosis processing, to process the dilute solution into: liquid refrigerant; and, strong or concentrated solution for an absorber arrangement, without an energy intensive step of processing the dilute solution through vaporizing the refrigerant. Providing the refrigerant via separation in liquid form, also avoids the need for the condenser step.

B. A Hypothetical Example (Using the Systems of FIGS. 3 and 3A) as Described in U.S. Provisional 61/280,105

This engineered example is provided to illustrate an example application of the invention and to illustrate the advantages of this method compared to the existing conventional, prior art methods. The example is based on the systems of FIGS. 3 and 3A. It is described as a cooling cycle.

For this example, assume an aqueous lithium bromide (LiBr) absorbent solution, used in an absorption refrigeration process in which the refrigerant is water. A LiBr solution was chosen for this example because at present it is a commonly used solution for absorption cycle based chillers and air conditioning equipment operating at standard AHR1 conditions.

For this example, assume that the cycle is operating at standard full load AHR1 conditions with an 85°F (29.4°C) condenser water entering temperature (line 104, FIG. 3) and a 44°F (6.7°C) chilled water leaving temperature (line 92, FIG. 3) with a flow rate of 3.0 gpm/ton (gallons per minute per ton, or 3.23 liters/minute per kW of cooling output) for the condenser water and 2.4 gpm/ton (2.58 liters/minute per kW of cooling output) for the chilled water. This example is based on a 958.5 ton (3370.9 kW of cooling) equivalent capacity water-cooled chiller producing chilled water.

For this example it is assumed that the absorbent solution is being processed at a fixed temperature of 90°F (32.2°C) through all stages in the RO (reverse osmosis) process FIG. 3A and the pressure drop in various ones of the conduits carrying solution, will be negligible. It has also been assumed that: partially bypassed (in dilute solution flow direction) RO (reverse osmosis) units B, D and F will have a solution flow related pressure drop of 7.5 feet of water column (168 mmHg) on both the high pressure and low pressure sides of the membrane arrangements; and, non-bypassed RO units, units A, C, E and G will have a solution flow related pressure drop of 15 feet of water column (336 mmHg) on the high pressure side of the membrane and a negligible pressure drop on the low pressure (water) side of the membrane.

For reverse osmosis units A, C, E and G, a unit such as the ITT PCI membrane B1 tubular membrane arrangement available from Membrane Specialists, Hamilton, Ohio 45015 can be used, modified as necessary to have a low pressure side inlet with appropriate structural modification for high pressure side flow and low pressure side isolation. For units B, D, and F, similar reverse osmosis units can be used, again modified as necessary to have a low pressure side inlet and with appropriate structural modification for high pressure side flow and low pressure side flow isolation. For reverse osmosis unit H, a reverse osmosis unit such as the TF-S® SS (single-stage) spiral wound membrane unit available from Koch Membrane Systems, Inc., Wilmington, Mass. 01887 can be used, without modification.

It is also assumed that the efficiency of each pump is 87% and that each motor is 92.5% efficient. Each pressure letdown device is assumed to be a turbine style power regenerative device which will be used to assist in the pressurization function that is being provided by each pressurization pump. It is assumed that the efficiency for each pressure letdown device is 77% effectiveness at converting the available pressure differential and flow rate into usable power. The example also assumes a driving differential pressure across the membrane arrangement in each reverse osmosis (RO) unit at a level which is 20% higher than the difference in osmotic pressures that would be ideally required for the two solutions exiting the high and low pressure sides of the RO unit. This extra pressure is typical of conventional RO systems as a means of providing moderate permeate flux rates and to also overcome the concentration gradients which will inherently exist in the solutions near the membrane wall. This engineered example is described assuming a steady state, steady flow condition. In this example all concentrations are presented as % by weight.

The dilute (aqueous LiBr) absorbent solution to be processed enters the (example reverse osmosis membrane unit) system 82 via conduit 84 at a concentration of 54.0% LiBr. The re-concentrated, or desorbed, solution which leaves the reverse osmosis membrane unit system via conduit 85 in system 82 of FIG. 3A is fed into the absorber 83 shown in FIG. 3 at a concentration of 55.75% LiBr. The approximate vapor pressure of the LiBr solutions being fed into, and out of, the absorber arrangement 83, FIG. 3, at an operating temperature of 90°F (32.2°C), are 5.1 (line 88) and 7.5 (line 84) mmHg (millimeter mercury) absolute, respectively. This represents an equivalent refrigerant vapor pressure of 35°F (1.67°C) and 45°F (7.22°C), respectively which would be sufficient to produce 44°F (6.67°C) chilled water, in line 92, FIG. 3, in this example. In the absorber arrangement 83, the refrigerant vapor, in this case water vapor, is absorbed. This creates a dilute solution (in sump 96) from the strong solution (line 88) that is fed into the absorber arrangement 83. The dilute solution is then removed from the absorber arrangement 83, at 84, and is passed via conduit 84, FIG. 3A into the (reverse osmosis membrane) unit system 82 for the desorption (separation) process.

The flow rate of vapor from the evaporator arrangement 90 to the absorber arrangement 83, FIG. 3, via line 95 is 187.3 #/min (84.96 kg/min) which corresponds to the flow rate of liquid refrigerant that is fed into the evaporator arrangement 90, via conduit 89, from conduit 86 of the
reverse osmosis membrane unit system 82, FIG. 3A. At an average evaporator temperature of 40°F. (4.4°C) and using water as a refrigerant which enters the evaporator arrangement at 90°F. (32.2°C), the water (refrigerant) has an enthalpy change from 90°F. (32.2°C) liquid to 40°F. (4.4°C) liquid, of 50 Btu/# (British thermal units/pound) 27.8 kcal/kg. At 187.3 #/min (84.96 kg/min) approximately 46.87 tons (164.8 kW) of cooling is lost in flash to cool the refrigerant liquid from 90°F. (32.2°C) to 40°F. (4.4°C) in the evaporator arrangement 90. The remaining heat energy absorbed in the evaporator arrangement 90 is used to change from a liquid to a slightly superheated refrigerant gas and serves as the useful cooling provided by the overall refrigeration cycle 80, FIG. 3. The heat uptake in the evaporator at these conditions would be 958.5 tons (3370.9 kW) of cooling.

[0113] The solution in conduit 84, FIG. 3A, is pressurized by pump 100 from an entering pressure in conduit 84 of 0.0967 Pounds per Square Inch Absolute (PSIA) (66.7 Ps) to a pressure of 41.1 PSIA (2.834 bar) at a flow rate of 5.967 Pounds per minute (#/min) (2706.6 kg/min) of solution in line 101. The solution comprises 3222 #/min (1461.5 kg/min) of solution (LiBr) and 2745 #/min (1245.1 kg/min) of solvent (water) and has a calculated osmotic pressure of 8578 PSIA (591.43 bar). The shaft power required of pump 100 at the assumed efficiencies would be 20 break horsepower (BHP) (14.91 kW).

[0114] The solution is conducted via conduit 106 to the low pressure side inlet of reverse osmosis unit 80. A flux of the water solvent will permeate through the membrane of reverse osmosis unit 80, causing a reduction in the solution concentration on the low pressure side 105 of the reverse osmosis unit 80 as it travels through that reverse osmosis unit 80 and exits via conduit 107. In this example the solution leaving reverse osmosis unit 80 via conduit 107 is receiving 3109 #/min (1410.2 kg/min) of permeated water as it is processed in reverse osmosis unit 80. At the same time, the solution on the high pressure side 105 of reverse osmosis unit 80 that entered via conduit 106 is being concentrated by the removal of the same amount (3109 #/min (1410.2 kg/min)) of permeated water before exiting via conduit 109. The pressure in conduit 107 is reduced from that in conduit 101 by the 15 feet water column (336 mmHg) of flow related pressure drop associated with this reverse osmosis membrane unit 80.

[0115] The solution exiting reverse osmosis unit 80 via conduit 107, now 35.5% LiBr by weight, is conveyed at a rate of 9076 #/min (4116.8 kg/min) and has a calculated osmotic pressure of 4288 PSIA (295.6 bar).

[0116] The flow in conduit 107 is directed to joint 118, where it is split into conduit 119 and conduit 116. Conduit 119 is part of a bypass line comprising conduits 119 and 121; and, pump 120. 78% of the total flow in conduit 107 is directed into conduit 119 while the remaining 22% of the flow from conduit 107 is directed into the, conduit 116. The flow in conduit 119 is directed to the high pressure side 115f of reverse osmosis unit 124, from joint 122 and conduit 198, via pump 120 and conduit 121. The flow in conduit 116 is directed into a low pressure side 115e of the reverse osmosis unit 124 where it is further processed.

[0117] A flux of the water solvent will permeate through the membrane arrangement 115 of reverse osmosis unit 124 causing a reduction in the solution concentration on the low pressure side 115f of the reverse osmosis unit 124 as it travels through that reverse osmosis unit 124 and exits via conduit 124.

[0118] In this example, the solution leaving reverse osmosis unit 124 is receiving 187.3 #/min (84.96 kg/min) of permeated water as it is processed in reverse osmosis unit 124. At the same time, solution on the high pressure side 115x of reverse osmosis unit 124 that entered via conduit 198 is being concentrated by the removal of the same amount (187.3 #/min (84.96 kg/min)) of permeated water before exiting via conduit 199. The pressure in conduit 124 is reduced from that in conduit 116 by the 7.5 feet water column (168 mmHg) of flow related pressure drop associated with reverse osmosis membrane unit 124. Because, in this example, the permeate flux rate through the partially bypassed reverse osmosis units B, D, and F is significantly less than the flux through the other non-bypassed, reverse osmosis units A, C, E, and G the physical surface area of these reverse osmosis units (B, D, and F) is anticipated to be smaller than the physical surface area of the non-bypassed reverse osmosis units (A, C, E, and G) as an approximation.

[0119] The solution exiting reverse osmosis unit 124 via conduit 124, now 32.46% LiBr by weight, is conveyed at a rate of 2184 #/min (990.6 kg/min) and has a calculated osmotic pressure of 3779 PSIA (260.6 bar).

[0120] The solution is then conducted via conduit 124 to the low pressure side conduit 130y inlets of reverse osmosis units C and C. A flux of the water solvent will permeate through the membrane 130 of reverse osmosis unit C, causing a reduction in the solution concentration on the low pressure side 130y of reverse osmosis unit C, as it travels through that reverse osmosis unit C and exits via conduit 133. In this example, the solution leaving reverse osmosis unit C via conduit 133 is receiving 709 #/min (321.6 kg/min) of permeated water as it is processed in reverse osmosis unit C. At the same time, solution on the high pressure side 130x of reverse osmosis unit C that entered via conduit 131 is being concentrated by the removal of the same amount (709 #/min (321.6 kg/min)) of permeated water before exiting via conduit 132. The pressure in conduit 133 is reduced from that in conduit 124, by the 15 feet water column (336 mmHg) of flow related pressure drop associated with reverse osmosis membrane unit C.

[0121] The solution exiting reverse osmosis unit C via conduit 133, now 24.5% LiBr by weight, is conveyed at a rate of 2893 #/min (1312.2 kg/min) and has a calculated osmotic pressure of 2611 PSIA (180.0 bar).

[0122] The flow in conduit 133 is directed to joint 135, where it is split into a first conduit 137 and a second conduit 136. The first conduit 137 is part of a bypass line comprising conduits 137 and 139, and pump 138. 68% of the total flow in conduit 133 is directed into conduit 137 while the remaining 32% of the flow from conduit 133 is directed into the second conduit 136. The flow in conduit 137 is directed to the high pressure side joint 196 via pump 138. The flow in conduit 136 is directed into the low pressure side inlet of reverse osmosis unit D where it is further processed.

[0123] A flux of the water solvent will permeate through the membrane arrangement 140 of reverse osmosis unit D, causing a reduction in the solution concentration on the low pressure side 140y of the reverse osmosis unit D as it travels through reverse osmosis unit D and exits via conduit 141. In this example, the solution leaving reverse osmosis unit D via conduit 141 is receiving 187.3 #/min (84.96 kg/min) of permeated water as it is processed in reverse osmosis unit D.
the same time, solution on a high pressure side $140\times$ of reverse osmosis unit D that entered via conduit $142$ is concentrated by the removal of the same amount (187.3 $\text{#/min (84.96 kg/min)}$) of permeated water before exiting via conduit $143$. The pressure in conduit $141$ is reduced from that in conduit $136$ by the 7.5 feet water column (168 mmHg) of flow related pressure drop associated with this membrane unit.

[0124] The solution exiting reverse osmosis unit D via conduit $141$ is now 20.38% LiBr by weight, is conveyed at a rate of $1113 \text{#/min (504.5 kg/min)}$, and has a calculated osmotic pressure of 2082 PSIA (143.5 bar).

[0125] The solution is then conducted via conduit $141$ to a low pressure inlet $151$, for low pressure side $150\times$ of reverse osmosis unit E. A flux of the water solvent will permeate through the membrane arrangement $150\times$ of reverse osmosis unit E, causing a reduction in the solution concentration on the low pressure side $150\times$ of reverse osmosis unit E as it travels through that unit E and exits via conduit $152$. In this example the solution leaving reverse osmosis unit E via conduit $152$ is receiving 507 $\text{#/min (230 kg/min)}$ of permeated water as it is processed in reverse osmosis unit E. At the same time solution on the high pressure side $150\times$ of reverse osmosis unit E that entered via conduit $153$ is concentrated by the removal of the same amount (507 $\text{#/min (230 kg/min)}$) of permeated water before exiting via conduit $154$. The pressure in conduit $152$ is reduced from that in conduit $141$ by the 15 feet water column (336 mmHg) of flow related pressure drop associated with this membrane unit.

[0126] The solution exiting reverse osmosis unit E via conduit $152$, now 14.06% LiBr by weight, is conveyed at a rate of 1620 $\text{#/min (734.8 kg/min)}$ and has a calculated osmotic pressure of 1345 PSIA (92.7 bar).

[0127] The flow in conduit $152$ directed to joint $156$ is split into conduit $158$ and conduit $157$. Conduit $158$ is part of a bypass line comprising conduits $158$ and $192$, and pump $191$. 80% of the total flow in conduit $152$ is directed into conduit $158$ while the remaining 20% of the flow from conduit $152$ is directed into the second conduit $157$. The flow in conduit $158$ is directed to the high pressure side joint $190$ via pump $191$. The flow in conduit $157$ is directed into the low pressure side $160\times$ of the reverse osmosis unit F where it is further processed.

[0128] A flux of the water solvent will permeate through the membrane arrangement $160\times$ of reverse osmosis unit F, causing a reduction in the solution concentration on the low pressure side $160\times$ of the reverse osmosis unit F as it travels through that unit F and exits via conduit $161$. In this example the solution leaving reverse osmosis unit F via conduit $161$ is receiving 187.3 $\text{#/min (84.96 kg/min)}$ of permeated water as it is processed in the reverse osmosis unit F. At the same time, solution on the high pressure side $160\times$ of reverse osmosis unit F that entered via conduit $162$ is concentrated by the removal of same amount (187.3 $\text{#/min (84.96 kg/min)}$) of permeated water before exiting via conduit $163$. The pressure in conduit $161$ is reduced from that in conduit $157$ by the 7.5 feet water column (168 mmHg) from flow related pressure drop associated with this membrane unit.

[0129] The solution exiting reverse osmosis unit F via conduit $161$, now 8.87% LiBr by weight, is conveyed at a rate of 511 $\text{#/min (231.8 kg/min)}$ and has a calculated osmotic pressure of 813 PSIA (56.1 bar).

[0130] The solution is then conducted via conduit $161$ to the low pressure side inlet $166$ of reverse osmosis unit G. A flux of the water solvent will permeate through the membrane arrangement $170\times$ of reverse osmosis unit G causing a reduction in the solution concentration on the low pressure side $170\times$ of the unit G as it travels through that unit G and exits via conduit $171$. In this example, the solution leaving reverse osmosis unit G via conduit $171$, is receiving 403 $\text{#/min (182.8 kg/min)}$ of permeated water as it is processed in reverse osmosis unit G. At the same time, solution on the high pressure side $170\times$ of reverse osmosis unit G that entered via conduit $172$ is concentrated by the removal of the same amount (403 $\text{#/min (182.8 kg/min)}$) of permeated water before exiting via conduit $173$. The pressure in conduit $171$ is reduced from that in conduit $161$ by the 15 feet water column (336 mmHg) from flow related pressure drop associated with reverse osmosis membrane unit G.

[0131] The solution exiting reverse osmosis unit G via conduit $171$, now 4.96% LiBr by weight, is conveyed at a rate of 915 $\text{#/min (415 kg/min)}$ and has a calculated osmotic pressure of 439 PSIA (30.27 bar).

[0132] The flow in conduit $171$ is directed to reverse osmosis unit H, a first, final, reverse osmosis unit in the reverse osmosis membrane unit system $82$, via pump $175$ and conduit $176$. The flow in conduit $171$ exits reverse osmosis unit G at a pressure of 5.4 PSIA (0.3723 bar) and is pressurized via pump $175$ to a pressure of 685.7 PSIA (47.3 bar) in conduit $176$. The calculated power input required at pump $175$ is 50 BHP. The pressurized solution in conduit $176$ flows into the high pressure side $180\times$ inlet of reverse osmosis unit H where it is further processed. A flux of the water solvent will permeate through the membrane arrangement $180\times$ of reverse osmosis unit H causing an increase in the solution concentration on the high pressure side $180\times$ of the unit H as it travels through that unit H and exits via conduit $182$.

[0133] The flux of permeate water through the membrane arrangement $180\times$ of reverse osmosis unit H is collected on the low pressure side $180\times$ of the membrane $180$, and is conveyed out of the reverse osmosis unit H via conduit $181$. It is directed to the evaporator arrangement $90$, FIG. 3, via conduit $86$ and $87$. The permeate leaving reverse osmosis unit H via conduit $181$ serves as the refrigerant liquid in the overall refrigerating cycle $80$, FIG. 3.

[0134] In this example, the refrigerant liquid leaving reverse osmosis unit H via conduit $181$ is conveyed at a rate of 187.3 $\text{#/min (84.96 kg/min)}$ and a pressure of 6.5 PSIA (0.4482 bar) and is assumed to be pure water at this point in the process cycle. The solution exiting reverse osmosis unit H via conduit $182$ is increased in concentration from that in conduit $176$ through the removal of permeate from the solution in the reverse osmosis membrane unit H. The concentration of the solution in conduit $182$ is 6.24% LiBr and has a calculated osmotic pressure of 558 PSIA (38.5 bar). The pressure in conduit $182$ is reduced from that in conduit $176$ by the 15 feet water column (336 mmHg) from flow related pressure drop associated with this membrane unit. The solution in conduit $182$ is conveyed into optional pressure reducing device $183$ where a pressure reduction could be provided if needed. In this example the flows on the system were balanced such that the use of this pressure reduction device $183$ is optional. In this example, the pressure drop across unit $183$ was calculated to be 2 feet of water column (44.79 mmHg). Therefore, the pressure of the solution in conduit $172$ is calculated to be 678 PSIA (46.75 bar).

[0135] The solution in conduit $172$ is conveyed to the high pressure side $170\times$ of reverse osmosis unit G where it is further concentrated to 14% LiBr upon exiting into conduit $171$. The solution exiting reverse osmosis unit G via conduit $171$, now 4.96% LiBr by weight, is conveyed at a rate of 915 $\text{#/min (415 kg/min)}$ and has a calculated osmotic pressure of 439 PSIA (30.27 bar).
The average calculated osmotic pressure on the high pressure side \(170x\) of the membrane arrangement \(170\) of reverse osmosis unit \(G\) is 951.5 PSI (65.6 bar). The calculated pressure in conduit \(173\) is 672 PSI (46.33 bar). The average calculated osmotic pressure of the solution on the low pressure side \(170y\) of the membrane arrangement \(170\) of reverse osmosis unit \(G\) is 626 PSI (43.16 bar). Thus, the difference in calculated average osmotic pressure between the solutions on the high pressure side \(170x\) and the low pressure side \(170y\) of the reverse osmosis membrane arrangement \(170\) of reverse osmosis unit \(G\) is 325.5 PSI (22.44 bar). The actual pressure difference between the high pressure side \(170x\) and the low pressure side \(170y\) is 667 PSI (45.99 bar), on average, in this calculated example. Thus, a flux of permeate water is able to pass through the reverse osmosis membrane arrangement \(170\) from the high pressure side \(170x\) to the low pressure side \(170y\): The maximum difference in osmotic pressure, on the more concentrated flow end of the reverse osmosis membrane unit \(G\) is between the flows entering via conduit \(166\) and exiting via conduit \(173\). The difference in osmotic pressures at this point is calculated to be 532 PSI (36.68 bar), which is less than the average actual operating pressure differential and thus a flux of permeate through membrane arrangement \(170\) can be achieved.

The solution in conduit \(173\) is conveyed at a rate of 324 \#/min (147 kg/min) to joint \(190\) where it is combined with flow of equal LiBr concentration from conduit \(192\). The combined flow from joint \(190\) is conveyed at a rate of 1620 \#/min (734.8 kg/min) into conduit \(162\) which serves to feed the solution to the high pressure inlet side \(160\) of reverse osmosis unit \(F\) for further processing. The pump \(191\) pressurizes the flow from conduit \(158\) such that it is able to feed into joint \(190\) at the desired flow rate. The calculated power input required at pump \(191\) is 68 BHP.

Reverse osmosis unit \(F\) further concentrates the solution flowing on the high pressure side \(160x\) of the membrane arrangement \(160\) from a concentration of 14% in conduit \(162\) to a concentration of 15.83% in conduit \(163\). The maximum difference in osmotic pressure is seen by the reverse osmosis unit \(F\), on the more dilute end between the solutions contained in conduits \(162\) and \(161\). The calculated difference in osmotic pressure between these two solutions is 532 PSI (36.68 bar). The actual operating pressure difference between these two solutions upon entering and exiting reverse osmosis unit \(F\) at this end of the reverse osmosis unit \(F\) is 660.8 PSI (45.56 bar), thus a net flux of permeate through the membrane arrangement \(160\) of unit \(F\) can be established.

The solution in conduit \(163\) is conveyed at a flow rate of 1433 \#/min (650 kg/min) to the high pressure side inlet \(153\) of reverse osmosis unit \(E\), where it is further concentrated to 24.5% LiBr, upon exiting into conduit \(154\) which corresponds to a calculated osmotic pressure of 2611 PSI (180.02 bar). The calculated pressure in conduit \(154\) is 663 PSI (45.71 bar) at a solution flow rate of 926 \#/min (420 kg/min). The maximum difference in osmotic pressure seen by the reverse osmosis unit \(E\) is on the more concentrated end between the solutions contained in conduits \(154\) and \(151\). The calculated difference in osmotic pressure between these solutions is 529 PSI (36.47 bar). The actual operating pressure difference between these two solutions upon entering and exiting reverse osmosis unit \(E\) at this end of the unit \(E\) is 611.3 PSI (42.15 bar). Thus a flux of permeate water is able to pass through the reverse osmosis membrane arrangement \(150\) of unit \(E\) from the high pressure side \(150x\) to the low pressure side \(150y\).

The solution in conduit \(154\) is conveyed to at a rate of 926 \#/min (420 kg/min) to joint \(196\) where it is combined with flow of equal LiBr concentration from conduit \(139\). The combined flow from joint \(196\) is conveyed at a rate of 2893 \#/min (1312.2 kg/min) into conduit \(142\), which serves to feed the solution to the high pressure side \(140x\) of reverse osmosis unit \(D\) for further processing. The pump \(138\) pressurizes the flow from conduit \(137\) such that it is able to feed into joint \(196\) at the desired flow rate. The calculated power input required at pump \(138\) is 101 BHP. Reverse osmosis unit \(D\) further concentrates the flow of solution on the high pressure side \(140x\) of the membrane arrangement \(140\), from a concentration of 24.5% in conduit \(142\) to a concentration of 26.2% in conduit \(143\). The maximum difference in osmotic pressure seen by the reverse osmosis unit \(D\) is on the more dilute end between the solutions contained in conduits \(142\) and \(141\). The calculated difference in osmotic pressure between these solutions is 529 PSI (36.47 bar). The actual operating pressure difference between these two solutions upon entering and exiting unit \(D\) at this end of the RO unit \(D\), is 641.3 PSI (44.21 bar). Thus a net flux of permeate through the membrane arrangement \(140\) of unit \(D\) can be established.

The solution in conduit \(131\) is conveyed at a flow rate of 2706 \#/min (1227.4 kg/min) to the high pressure side \(130x\) of reverse osmosis unit \(C\), where it is further concentrated to 35.5% LiBr upon exiting into conduit \(132\), which corresponds to a calculated osmotic pressure of 4288 PSI (295.65 bar). The calculated pressure in conduit \(132\) is 653.2 PSI (45.04 bar) at a solution flow rate of 1997 \#/min (905.8 kg/min). The maximum difference in osmotic pressure seen by the reverse osmosis unit \(C\) is on the more concentrated end between the solutions contained in conduits \(132\) and \(124\). The calculated difference in osmotic pressure between these solutions is 509 PSI (35.09 bar). The actual operating pressure difference between these two solutions upon entering and exiting unit \(C\) at this end of unit \(C\) is 621.8 PSI (42.87 bar). Thus, a flux of permeate water is able to pass through the reverse osmosis membrane arrangement \(130\) of unit \(C\) from the high pressure side \(130x\) to the low pressure side \(130y\).

The solution in conduit \(132\) is conveyed to joint \(122\) where it is combined with flow of equal LiBr concentration from conduit \(121\). The combined flow from joint \(122\) is conveyed at a rate of 9076 \#/min (4116.8 kg/min) into conduit \(198\) which serves to feed the solution to the high pressure side \(115x\) of reverse osmosis unit \(B\) for further processing. The pump \(120\) pressurizes the flow from conduit \(119\) such that it is able to feed into joint \(122\) at the desired flow rate. The calculated power input required at pump \(120\) is 350 BHP. Reverse osmosis unit \(B\) further concentrates the flow of solution on the high pressure side \(115x\) of the membrane arrangement \(115\) from a concentration of 35.5% in conduit \(198\) to a concentration of 36.25% in conduit \(199\). The maximum difference in osmotic pressure seen by the reverse osmosis unit \(B\) is on the more dilute end between the solutions contained in conduits \(198\) and \(124\). The calculated difference in osmotic pressure between these solutions is 509 PSI (34.54 bar). The actual operating pressure difference between these two solutions upon entering and exiting unit \(B\) at this end of the unit \(B\) is 617.1 PSI (42.548 bar). Thus, a net flux of permeate through the membrane arrangement of unit \(B\) can be established.
The solution in conduit 199 is conveyed at a flow rate of 8889 #/min (4032 kg/min) to the high pressure side 105x of reverse osmosis unit A via pump 200. Upon leaving the unit A, liquid on the high pressure side 105x of the reverse osmosis membrane arrangement 105, has been further concentrated to 55.75% LiBr upon exiting into conduit 109 which corresponds to a calculated osmotic pressure of 9146 PSIA (630.59 bar). Pump 200 serves to increase the pressure of the solution as it is conveyed from conduit 199 into conduit 108. Pump 200 increases the pressure from 645.3 PSIA (44, 492 bar) in conduit 199 to a pressure of 737 PSIA (50.81 bar) in conduit 108. The calculated pumping power required for pump 200 is 66 BHP. The maximum difference in osmotic pressure seen by the reverse osmosis unit A is on the more concentrated end between the solutions contained in conduits 109 and 101. The calculated difference in osmotic pressure between these solutions is 568 PSI (39.16 bar). The actual operating pressure difference between these two solutions upon entering and exiting unit A at this end of the unit A is 689.4 PSI (47.53 bar). Thus a flux of permeate water is able to pass through the reverse osmosis membrane arrangement 105 of unit A from the high pressure side 105x to the low pressure side 105y:

The solution in conduit 109 is then conveyed to a pressure reduction device 110. This device reduces a solution flow of 7466 #/min (3386.2 kg/min) from a pressure of 730 PSIA (50.332 bar) to 9 PSIA (0.6205 bar), and would produce a shaft power output of 225 BHP which could be used to offset some of the power consumption of the other pumps in the system 82.

In general, the flow of solution increases in concentration along the high pressure side path from conduit 176 through unit H, into conduit 182, through pressure reduction device 183, into conduit 172, and then through the high pressure sides for units G, F, E, D, and B, pump 200, and then through unit A; while, conversely, the flow of solution from conduit 101 generally decreases in concentration following the low pressure side path of unit A through units B, C, D, E, F, and G, then prior to entering the final reverse osmosis membrane unit 11 in the membrane unit system 82 with the various joints, bypasses, and pressurization changes as previously described herein. Herein such a process is referenced as a cascading reverse osmosis process, although the number of RO units can be varied.

The results of this engineered example indicate a total net power input requirement of 654 shaft BHP via reverse osmosis pumps 100, 175, 191, 138, 120 and 200, and a total power generated via pressure letdown device 110 of 225 shaft BHP, for a net total system power input requirement of 429 shaft BHP. Using the assumed electrical motor efficiencies of 92.5%, this equates to a total power input requirement of 346 kW to produce 958.5 tons (3370.9 kW) of cooling which represents a system full load efficiency of 0.36 kW/ton (0.10236 kW of energy input/kW of cooling produced).

In comparison, a present state of the art vapor compression water cooled centrifugal chiller operates in the range of approximately 0.60 kW/ton (0.1706 kW of energy input/kW of cooling produced) under these same stated operating conditions. This example indicates that the absorption osmosis refrigeration cycle 80, FIG. 3, has the potential to operate using 40% less energy than a present state of the art vapor compression refrigeration cycle. In this example if one were to assume that this chiller were to operate as a base loaded machine operating at full load under these conditions for 6500 hours per year the electrical consumption savings would be approximately 1,495,260 kWh per year. If this electrical energy were to be purchased for $0.085/kWh that would equate to an annual operating cost savings of $127,097. Additional calculations of other configurations of the (reverse osmosis membrane unit) system 82 indicate that by adding more membrane stages, the system 82 has the ability to produce a cycle that operates with an even lower overall energy consumption per ton (3.517 kW) of cooling than was demonstrated in the example presented here.

A further comparison could be made to a present state of the art water cooled absorption cycle operating as a chiller under the same stated conditions. Because the prior art absorption cycles are predominately thermally driven (also known as heat driven) cycles a comparison to the reverse osmosis absorption cycle is not as direct. As stated above, a typical present day single stage absorption chiller operates with a cooling Coefficient Of Performance (or COP) in the range of 0.83 to 1.0, where COP is the ratio of the cooling energy produced divided by the input energy required to drive the cycle. This example indicates that the absorption osmosis refrigeration cycle 80, FIG. 3, has the potential to operate at an energy input rate of 546 kW to produce 958.5 tons (3370.9 kW) of cooling. This equates to an operational COP of 9.74 which is approximately a 10 times greater efficiency than standard water cooled absorption cycle as described herein. Although the energy efficiency of the standard absorption cycle is poor, sources of thermal energy are typically less expensive than electrical or mechanically driven sources of energy input. This explains why the standard, thermally driven, absorption cycle is still in common use for certain applications where abundant relatively high temperature waste heat is readily available. The comparison against the vapor compression cycle is more appropriate due to its similarity in terms of being driven from mechanical work (primarily electric motor driven), rather than being predominately thermal or heat driven as is the case in the standard absorption cycle. A standard absorption cycle could be driven with electrically generated heat, however the very poor efficiency and the relatively high price of electricity makes this concept impractical especially given the fact that a vapor compression cycle is less expensive in terms of initial equipment cost and is significantly more energy efficient than the standard absorption cycle.

If the energy savings potential of this cycle 80 were to be achieved in many applications on a wide scale, the impact on the world’s electrical consumption for cooling could be notably improved over the present state of the art vapor compression refrigeration cycles. In addition, because the example described application uses water as a refrigerant many of the environmental and safety concerns associated with other commonly used refrigerants such as ozone depletion, global warming potential, flammability, or toxicity are avoided.

C. Some Comments Updating the Hypothetical Example of Section IV. B.

Since the patent Provisional submittal it has been found that it is appropriate for a correction factor to be applied to the calculation of osmotic pressure. This correction factor is appropriately applied when working with highly active ions (such as lithium) or when working with non-dilute solutions. Under these conditions, the solution can behave in a non-ideal
manner and produce actual osmotic pressures which deviate from values calculated using traditional uncorrected methods. To account for this, a factor is applied to the calculation of osmotic pressure which is known as the Osmotic Coefficient. This Osmotic Coefficient is a function of temperature, concentration, and the ionic strength (or the solute activity coefficient). The values expressed in the preceding Hypothetical Example, from U.S. Ser. No. 61/280,105, were made without correcting for this Osmotic Coefficient.

V. A Modified Application of the Techniques Described in Connection with FIGS. 3 and 3A; FIG. 3B

A. Use of a Second Example Reverse Osmosis Unit System—FIG. 3B

[0150] In the previous description, an example absorption osmosis refrigeration cycle 80, FIG. 3, was described. In the system, a membrane-based processing unit system for non-vaporizing solution processing system 82, in particular a reverse osmosis membrane unit system, was described as used, in place of a traditional desorber (55). FIG. 2, and condenser 32, FIG. 2, to process dilute solution from the absorber arrangement 83 into a strong solution for the absorber loop, and, a refrigerant liquid for the evaporator arrangement 90. It was described that the (example reverse osmosis membrane unit) system 82 can be a variety of systems with advantages being derived from the lack of a step of separating refrigerant, from the dilute solution, by conversion to vapor (gas), with a comitant input of energy. Indeed, the processing of the dilute solution in the (reverse osmosis membrane unit) system 82 is conducted by using a reverse osmosis process.

[0151] Herein above, it was explained that a wide variety of processes involving reverse osmosis practices can be applied. An example was described in connection with FIG. 3A. Here a cascading reverse osmosis membrane system was described as example system 82, in which the dilute solution from the absorber 83, FIG. 3, was directed, initially, into a low pressure side of a first, final, reverse osmosis membrane unit A.

[0152] Alternate reverse osmosis membrane unit systems can be used. Indeed, in some systems the dilute solution from the absorber arrangement 83 can be directed into the high pressure side of a first reverse osmosis membrane unit system. An example of this is provided in this section.

[0153] Referring to FIG. 3B, a reverse osmosis membrane unit system 82', usable as system 82, FIG. 3, for processing dilute solution from line 84, in refrigeration cycle 80, is shown. Referring to FIG. 3B, dilute solution input to system 82' is shown at line 84 with: (a) strong solution output from system 82' shown at line 85, and (b) refrigerant liquid output from system 82' shown at line 86.

[0154] Referring to FIG. 3B, for the example system 82' depicted, dilute solution 84 is directed into pump 300, and then into pressurized line 301, which serves as a high pressure side inlet line for reverse osmosis unit L. Reverse osmosis unit L comprises a reverse osmosis membrane arrangement 305 having a high pressure side 305x and a low pressure side 305y.

[0155] A high pressure side outlet from unit L is shown at 306, comprising concentrated or strong solution directed through pressure reduction device 307 into line 85.

[0156] Low pressure side outlet from reverse osmosis unit L is shown at 310 being directed through pump 311 into line 312 which serves as a low pressure side inlet for reverse osmosis unit M.

[0157] Reverse osmosis unit M comprises a reverse osmosis membrane arrangement 315 having a high pressure side 315x and a low pressure side 315y. Low pressure side outlet from reverse osmosis unit M is shown at line 316 being directed to joint 317. At joint 317, the low pressure side outlet flow from unit M is split into lines 318, 319. Line 319 is directed through pump 320 into line 321.

[0158] Line 318, serves as a low pressure side inlet line for reverse osmosis unit N.

[0159] Reverse osmosis unit N comprises a reverse osmosis membrane arrangement 325 having a high pressure side 325x and a low pressure side 325y. Low pressure side outlet from reverse osmosis unit N is shown at line 326 directed to reverse osmosis unit O as a low pressure side inlet.

[0160] In general, reverse osmosis unit O comprises a reverse osmosis membrane arrangement 335 having a high pressure side 335x and a low pressure side 335y. Low pressure side outlet flow from reverse osmosis unit O is shown at line 337 being directed to joint 338 where it is separated at lines 339, 340. Line 340 is directed through pump 341 into line 342.

[0161] Line 339 operates as a low pressure side inlet line for reverse osmosis unit P. Reverse osmosis unit P comprises a reverse osmosis membrane arrangement 345 having a high pressure side 345x and a low pressure side 345y. A low pressure side outlet flow from reverse osmosis unit P is shown at line 347, which serves as a low pressure side inlet line for reverse osmosis unit Q.

[0162] In general, reverse osmosis unit Q comprises a reverse osmosis membrane arrangement 355 defining a high pressure side 355x and a low pressure side 355y. Low pressure side outlet flow from reverse osmosis unit Q is shown at line 356 directed to pump 357 and into line 358, which serves as a high pressure side inlet line for reverse osmosis unit R.

[0163] Reverse osmosis unit R comprises a reverse osmosis membrane arrangement 365 defining a high pressure side 365x and a low pressure side 365y. Permeate on the low pressure side 365y comprises purified solvent, i.e., refrigerant liquid, is shown leaving the reverse osmosis unit R at low pressure side outlet 366, to exit the system 82' and enter the refrigeration cycle 80 at refrigerant liquid line 86.

[0164] A high pressure side outlet line from reverse osmosis unit R is shown at 368 directed to optional pressure let-down device 369 to be directed into line 370 which operates as a high pressure side inlet line to reverse osmosis unit Q.

[0165] A high pressure outlet line from reverse osmosis unit Q is shown at line 371 where it is directed to joint 372 and is combined with liquid in line 342. The combined liquid enters line 373, a high pressure side inlet line for reverse osmosis unit P.

[0166] The high pressure side outlet from reverse osmosis unit P is shown at line 375 being directed as a high pressure side inlet for reverse osmosis unit O.

[0167] A high pressure side outlet from reverse osmosis O is shown at line 378 being conveyed to joint 379 where it is joined with liquid from line 321 and directed into line 380.

[0168] Line 380 serves as a high pressure side inlet line from reverse osmosis unit N. A high pressure side outlet line from reverse osmosis unit N is shown at line 381 being directed into reverse osmosis pump 382, and then into a
higher pressurized line 383 which serves as a high pressure side inlet line to reverse osmosis unit M.

[0169] A high pressure side outlet flow from reverse osmosis unit M is shown at line 385 being directed to optional pressure let-down device 386 and then into line 387 which serves as a low pressure side inlet line to reverse osmosis unit L.

[0170] It is noted that the reverse osmosis membrane unit system 82, FIG. 3B, can also be characterized as having: first, final, concentrate-generating reverse osmosis unit L; a first, final, solvent dilute solution-generating reverse osmosis membrane unit M; and, an intermediate reverse osmosis membrane unit system comprising units M, N, O, P, and Q. Further unit M can be characterized as a final, concentrate flow direction, or first dilute purified solvent flow direction, reverse osmosis unit of the intermediate reverse osmosis membrane unit system; and, unit Q can be characterized as the final solvent or dilute solution flow direction, or first concentrate flow direction, reverse osmosis membrane unit of the intermediate reverse osmosis membrane unit system. Further, the processing conducted by this reverse osmosis membrane unit system 82, FIG. 3B, can be generally characterized as above.

B. A Hypothetical Example using the Reverse Osmosis Unit System of FIG. 3B, with the Absorption Osmosis Refrigeration Cycle of FIG. 3

[0171] FIG. 3B presents a schematic view of another embodiment of a cascading RO membrane system that could be used as system 82, FIG. 3, to separate the refrigerant liquid from the dilute absorbent solution. In this configuration the dilute solution leaving the absorber arrangement 83, FIG. 3 in conduit 84 is pressurized and conveyed via pump 300, FIG. 3B, to the high pressure inlet of the reverse osmosis membrane unit L via conduit 301. The pressure of the solution on the adjacent side to membrane arrangement is such that a flux of solvent is transported through the membrane 305 of unit L from the side of high pressure 305x to the side of lower pressure 305y, thereby re-concentrating the solution from conduit 301 as it passes through unit L and exits into conduit 306. The now diluted solution on the low pressure side 305y of the reverse osmosis membrane unit L exits unit L via conduit 310. In this scenario the flow in conduit 310 follows a similar processing path as described for FIG. 3A. However in contrast to FIG. 3A there is a first processing of dilute solution from the absorber arrangement 83 of FIG. 3A, via first entering the high pressure side of a reverse osmosis membrane unit.

[0172] The re-concentrated solution in conduit 306 then passes through a pressure let down device 307 where additional power may be generated as the solution moves into conduit 85. The solution in conduit 85 is then transferred back to the inlet side of the absorber arrangement 83, as is generally depicted in FIG. 3.

[0173] It is noted that the number, and arrangement of, the membrane unit systems both in: FIG. 3A; and, FIG. 3B, is representative of example possibilities only. Both the number of, and the configuration of, the various stages of the reverse osmosis units can be arranged in a variety of configurations. What has been depicted here is merely intended to illustrate that multiple configurations for the RO Membrane Unit System 82 depicted in FIG. 3 are possible.

[0174] The arrangement depicted in FIG. 3B can be useful as a means of isolating the solute, or solute solution, from the remainder of the RO unit system. Because only solvent is passed through the RO membrane of unit L, the solvent solute mixture on the low pressure side of unit L, and the rest of the system for that matter, could consist of different solute than is present on the high pressure side of unit L which includes the absorber side of the system. This configuration could be used for a number of reasons. Reasons could be that the solution used in the absorber could possess properties, such as low pH or high corrosivity, which would require the use of a relatively expensive RO membrane unit system. By using the configuration of FIG. 3B an alternative solute could be used for the remainder of the system whereby RO membrane units of relative lower cost as compared to unit L could be deployed on the lower pressure side of RO membrane unit L in the system due to the ability of this system to use a less demanding solute solution at the lower concentration ranges that would be seen on the remainder of the system.

VI. Solvents, Solutes, and Solutions

[0175] There are a multitude of solvent, solute, and ultimate solution variations capable of being used in an absorption refrigeration cycle or system of the present disclosure with any of a variety of non-vaporizing solution processing techniques. Some examples of potential solutes include: potassium chloride, potassium bromide, potassium fluoride, sodium chloride, sodium bromide, sodium iodide, lithium chloride, lithium bromide, sodium sulphide, sodium formate, calcium chloride, calcium bromide, magnesium chloride, calcium hydrogen malate, sodium tetradecanoate, sodium phosphate, ammonium bicarbonate, disodium orthophosphate, propylene glycol, ethylene glycol, dimethylacetamide (DMAC) and mixtures thereof, although alternatives are possible. In practice any solute which disassociates into a solution with have the effect of lowering the vapor pressure of that solution while at the same time raising an osmotic pressure of the solution. Solutes could be used individually or in various combinations to produce the desired results. Mixtures of solutes could be used to produce many useful properties of the solution such as: reduced corrosivity, lowered propensity towards solute precipitation out of solution, viscosity, thermal conductivity, pH adjustment of the solution to a more desirable level, and/or reduced solution cost.

[0176] Some examples of potential solvents that could be used in the system of the present disclosure include: water, ammonia, various alcohols, refrigerant R-134a and mixtures thereof, although alternatives are possible. Solvents can be used individually or in various combinations to produce the desired results. Solute mixtures can be used to produce desired properties or operating conditions. For example, one could use a water/ethanol mixture or ammonia as a refrigerant in the cycle which would have a lower temperature freezing point than pure water, and thus could be used in applications where sub-freezing (<32°F or <0°C) temperatures are expected.

[0177] Further a mixture of solutes and a mixture of solvents can be in the present invention. One example of this could be illustrated by the use of a combination of water, ethanol, propylene glycol, and sodium iodide.

VII. Some Example Alternate Cycles, FIGS. 4-6

[0178] The general principles characterized above can be applied in a variety of alternately configured systems. Alternate configurations can be used for each (or both) of: the non-vaporizing solution processing based unit or system 82; and, remaining features of the absorption osmosis refrigeration process.
tion cycle 80, FIG. 3. Examples are provided herein, in FIGS. 4-6. These figures are illustrative that a wide variety of alternate configurations are possible.

A. A First Alternate Refrigeration Cycle, FIG. 4

Reference numeral 400, FIG. 4, depicts a first alternate refrigeration cycle. The cycle 400 has some features in common with cycle 80, FIG. 3, as follows. From non-vaporizing solution processing unit system 82, a refrigerant line (i.e. purified solvent line) 86 is shown. The line 86 includes liquid directed to refrigerant liquid line 87 for (first) evaporator arrangement 90, in this instance after passage through (optional) expansion or pressure reduction device 401 as flow from line 402. Heat input to the evaporator arrangement 90, to vaporize some or the entire refrigerant, is shown at arrows 91 with a cooled air or liquid output shown at 92. [0180] Within the evaporator arrangement 90, at least a portion of the refrigerant liquid is vaporized, with refrigerant gas (vapor) shown leaving evaporator arrangement 90 at line 95, by which it is directed into (first) absorber arrangement 83. In absorber arrangement 83, the refrigerant vapor is absorbed into strong solution, resulting in dilute solution in sump 96. Dilute solution outlet flow from sump 96 is shown at line 403 which, in part, provides liquid at line 84, as dilute solution input to the reverse osmosis membrane unit system 82. In the particular example depicted in FIG. 4, reverse osmosis pump 405 is depicted receiving liquid from line 84. In some instances, the pump 405 would be considered part of the non-vaporizing solution processing unit system 82; see for example analogous pump 100, FIG. 3A. [0181] Referring again to FIG. 4, at joint 410, a portion of the liquid refrigerant from line 86 is shown directed into a line 411, through expansion or pressure reduction device 412, and into a coolant line 413 for absorber arrangement 83. (It is also noted that absorber arrangement 83 is depicted with packing 83x.) [0182] Output from line 413, from absorber 83, comprising heated material in line 413, is shown at line 415, analogous to FIG. 3. This line, comprising heated (typically at least partially vaporized) refrigerant, is now shown being directed to a second absorber arrangement 420, with packing 420x, where it is absorbed into strong solution, resulting in the dilute solution shown in sump 421. The dilute solution from absorber arrangement 420 is shown being directed via line 425 to joint 426 where it is combined with the dilute solution output from absorber arrangement 83, to form the dilute solution line 84 directed to the (reverse osmosis membrane) non-vaporizing solution processing system 82. [0183] It is noted that, together, first absorber arrangement 83 and second absorber arrangement 420 can be considered an “absorber arrangement” for the system 400, in general accord with characterizations described herein. [0184] Strong or concentrated solution outlet from the non-vaporizing solution processing system 82 is shown at line 85. It is depicted directed through pressure reduction device 430 and into line 431. It is noted that an analogous pressure reduction device 430 in previous characterizations, was described as a portion of the (reverse osmosis membrane) non-vaporizing solution processing system 82, and it could be included as such here; see for example unit 110, FIG. 3A. [0185] The strong solution is directed to joint 432 where it is split into lines 433 and 434. Line 433 is directed into (first) absorber arrangement 83, and in particular to sprayer 435. Line 434 is directed into a absorber arrangement 420 and in particular to sprayer 436. Within absorber 420, the strong solution is directed into proximity with cooling loop 440, to heat material in the cooling loop. [0186] Fluid inlet to cooling loop 440 is shown entering the absorber 420 at line 445. Heated outlet from loop 440 is shown leaving absorber 420 and line 446. Pump 447 is depicted to facilitate operation of the loop 440. [0187] In general, the system 400 of FIG. 4 shows that heat recovered in the absorber arrangement 83 in a refrigeration cycle similar to that depicted in FIG. 3, can be absorbed by refrigerant liquid directed into absorber arrangement 420, for increasing refrigeration cycle efficiency. It is noted that a variety of alternate equipment configurations pump and pressure let down configurations and line configurations can be used. Further, no specific structural feature with respect to such equipment as the absorber arrangement or the evaporator arrangement in meant.

C. The Example System of FIG. 5

[0188] In FIG. 5 a second alternate variation is depicted, in absorption osmosis refrigeration cycle 500. Again, many features are analogous to ones described in connection with FIGS. 3 and 4. [0189] Referring to FIG. 5, within system 500 is provided a (for example membrane-based) non-vaporizing solution processing unit system 82, for example a reverse osmosis membrane unit system. Purified solvant (refrigerant) outlet flow from system 82 is shown in line 86 as eventually directed as refrigerant liquid inlet line 87 for (first) evaporator arrangement 90 after passage (with flow from line 502) through pressure drop-down or expansion, or pressure reduction, device 501. [0190] Within the evaporator arrangement 90, the refrigerant liquid is at least partially converted to a vapor (gas) phase, leaving the evaporator arrangement 90 at line 95. Heat input for the evaporator arrangement 90 is shown at lines 91. Cooled gas or liquid output from evaporator arrangement 90 is shown at line 92. [0191] The refrigerant gas (vapor) in line 95 is shown directed into (first) absorber arrangement 83, where it is absorbed by strong solution to generate dilute solution, shown in sump 96. Dilute solution is shown leaving the absorber through line 503, to be directed as a dilute solution into (membrane-based processing) non-vaporizing solution processing system 82. In the example depicted, reverse osmosis pump 505 is depicted. Pump 505 could also be considered a portion of system 82, see for example pump 100, FIG. 3A. [0192] Referring to joint 510, a portion of the dilute solution outlet from the system 82, via line 86, is shown directed via line 511 through pressure drop-down or expansion device 512 and into a coolant line 513 within (first) absorber arrangement 83. Here the refrigerant absorbs heat and is at least partially converted to a vapor. The refrigerant (typically gas) outlet from absorber cooling circuit 514 comprising line 513, is shown at line 515. It is noted that to facilitate increased surface area (and refrigerant absorption) within absorber arrangement 83, packing 83x is depicted. [0193] Refrigerant (at least partially gas or vapor) in line 515 is now directed to absorber arrangement 420, with packing 420x. Here it is absorbed into “extra” strong solution in absorber arrangement 420, forming dilute solution in sump 421. Dilute solution outlet flow from absorber arrangement 420 is shown at line 520, being directed to (for example reverse osmosis membrane unit arrangement) non-vaporiz-
ing solution processing unit system 82b. Within FIG. 5, reverse osmosis pump 521 is depicted. Pump 521 could be considered part of the arrangement 82b.

A diluted solution from (example reverse osmosis membrane) non-vaporizing solution processing unit system 82b is shown at line 525 being directed into (reverse osmosis membrane unit) non-vaporizing solution processing system 82.

Strong (concentrated) solution outlet flow from system 82 is shown at line 85 being directed through pressure let-down device 530 into line 531 where it is directed to joint 532. Here the strong solution is split, a portion being directed via line 533 as strong solution inlet flow to absorber arrangement 83, in the example depicted via sprayer 535. Also, from joint 532 a portion of strong solution is directed via line 540 into membrane-based processing unit system 82b, where it will receive permeate refrigerant from the absorber solution circuit of second absorber arrangement 420.

Extra concentrated or strong solution outlet from the membrane-unit processing unit system 82b is shown being directed via line 550 to pressure let-down or reduction device 551. This will generate in line 552 an “extra” strong solution, relative to the solution of line 533, for direction into absorber arrangement 420. In the example depicted, the extra strong solution is directed to sprayer 556.

Associated with absorber 420 is a heat transfer loop 440 that receives heat from the refrigerant absorption process in absorber 420. To facilitate refrigerant absorption packing 420x is provided.

Fluid input to loop 440 is shown at line 445, with heated fluid outlet being shown at line 446, and circulation being facilitated by pump 447.

In general, FIG. 5 depicts the principles of FIG. 4, relating to using energy output from one absorber to further evaporate refrigerant, for outlet flow in a second absorber arrangement, in combination with using a staged reverse osmosis membrane unit system, to generate a concentrated solution for operation of one absorber arrangement and an extra concentrated solution for operation of another. This example then demonstrates how selected principles characterized can be used to even a greater advantage in some instances.

It is noted that absorber arrangement 83 and absorber arrangement 420 can be, in accord with the terminology used herein, collectively referred to as an absorber arrangement. Further, it is noted that processing unit system 82 and processing unit system 82b can be, in accord with terminology used herein, collectively referred to as a non-vaporizing solution processing (unit) system.

It is noted that a wide variety of specific equipment configurations and types, pump and pressure let-down devices and types, and conduits (lines) types and configurations can be used. Further locations selected equipment is a variable of choice for a preferred efficiency, and in some instances alternate numbers or locations of specific equipment such as pumps, pressure let-down devices, etc. is possible.

D. A Third Alternate Example System, FIG. 6

In FIG. 6, yet another example alternative configuration of equipment is depicted, for an advantageous refrigeration cycle. Referring to FIG. 6, refrigeration cycle 600 is generally depicted. Attention is directed to non-vaporizing solution processing (unit) system 82. From system 82, a process solvent (refrigerant) outlet line is shown at line 86 being directed in part to a liquid refrigerant line 87 for (first) evaporator arrangement 90. It is noted that before being transferred into evaporator arrangement 90, the liquid of line 87 depicted is passed, via line 602, through pressure reduction device 401.

In evaporator arrangement 90, at least a portion of the refrigerant liquid is vaporized. From evaporator arrangement 90, vaporized (gaseous) refrigerant is shown leaving via line 95. Heat input to the evaporator arrangement 90, to cause vaporization of the refrigerant, is shown at line 91; with cooled fluid (gas or liquid) outlet from evaporator arrangement 90 being shown at line 92.

The refrigerant vapor of line 95 is shown being directed into (first) absorber arrangement 83, where it is absorbed into a strong solution, to form diluted solution shown in sump 96. From absorber arrangement 83, the resulting dilute solution outlet is shown at line 403 being directed into the (for example membrane-based) non-vaporizing solution processing unit system 82, in this example through a depicted pump 405. It is noted that the pump 405 could be a reverse osmosis pump considered a portion of the reverse osmosis membrane unit system, see pump 100, FIG. 3A.

Attention is now directed to joint 410, at which a portion of the liquid refrigerant from line 86, i.e. from the non-vaporizing solution processing (unit) system 82, is shown directed via line 411 and through expansion device or pressure let down device 412, into loop 413. Heat is transferred into the refrigerant in loop 413, within the absorber arrangement 83, including packing 83x, with the outlet line at 415 from absorber arrangement 83 comprising a refrigerant (gas or at least partially vaporized) outlet line. The vapor from line 415 is directed into absorber arrangement 420 with packing 420x, where it is combined with the extra strong solution in absorber arrangement 420 to provide a dilute extra strong solution or strong solution at 610. This strong solution is shown directed from absorber arrangement 420 via line 611 as a strong solution inlet to absorber arrangement 83, in the example depicted by sprayer 612.

Absorber arrangement 83 is depicted with optional packing 83x to facilitate absorption by increasing the surface area of the absorptive solution in absorber arrangement 83.

Referring again to membrane-based processing unit system 82, strong solution outlet from system 82 is shown at line 85 directed to joint 620. Here a portion of the concentrated solution or strong solution from system 82 is shown directed via line 630 as input to (for example membrane-based) non-vaporizing solution processing unit system 82b. Extra concentrated outlet flow from (for example reverse osmosis membrane) non-vaporizing unit system 82b is shown directed via line 640, through pressure reduction device 641, into line 652, as extra strong solution inlet to an absorber arrangement 420. In the example depicted, the inlet is shown provided by sprayer 636.

Diluted solution outlet from system 82b is shown directed via line 655 into (for example reverse osmosis) non-vaporizing solution processing (unit) system 82 for further processing.

A portion of the liquid in line 85, comprising concentrated solution from system 82 is shown being directed via line 656, through pressure reduction device 657 into line 658, a liquid flow inlet line to reverse osmosis membrane unit system 82a, for further processing.

Referring now to absorber arrangement 420, attention is directed to loop 440, which contains fluid (liquid or
(gas) heated within the absorber 420. Optional packing 420x facilitates increased surface area of the absorbent solution in absorber arrangement 420.

[0211] Fluid inlet to loop 440 is shown at line 445, with heated fluid outlet shown at 446. Circulation is facilitated by pump 447.

[0212] It is noted that system 82 and system 825 can be considered, together, to be a non-vaporizing solution processing (unit) system 82c. Also, absorber arrangement 83 and absorber arrangement 420 can be, in accord with terminology used herein, collectively referenced as an “absorber arrangement.”

[0213] The variation of FIG. 6 depicts how the principles of FIGS. 4 and 5 can be used together, along with directing extra strong solution to series through a first absorber arrangement and then into a second absorber arrangement, with step wise solution, for efficient operation.

[0214] Again it is noted that a variety of options from the specific equipment configuration and line configurations of FIG. 6 can be used. Equipment can be alternately located and in some instances pump and pressure let down device use is optional.

VIII. Some Alternate Solution Processing Techniques, to Reverse Osmosis Processing

A. General

[0215] As indicated above, in general refrigeration cycle systems, equipment and techniques according to the present disclosure use “non-vaporizing solution processing” for processing of the solution into a more purified solution stream (for refrigerant recovery and/or a more concentrated solution stream for strong solution regeneration). Reverse osmosis processing was discussed above, as an example of a membrane-based solution processing for application in such systems. However, membrane-based processing need not be limited to reverse osmosis processing, and the term is meant to include within its scope any processing in which a membrane or membrane arrangement unit is used to facilitate the processing, as an alternative to refrigerant vaporization and recondensation.

[0216] Also, as noted above, alternate non-vaporizing (i.e. non-phase change) solution processing techniques can be used, other than mere “membrane-based solution processing” as the term was used herein above. An example type of a non-vaporizing solution processing technique characterized above, was applied electric field processing. Again, the term “applied electric field processing” is meant to refer to any solution processing system, in which the solution is subjected to an applied electric field, which facilitates migration of solute or selected solute material, to effect generation of a reduced solute solvent (i.e. purified solvent). Examples of applied electric field processing techniques include: electrodialysis; electrodereionization; capacitive deionization; and, membrane capacitive deionization. However, the term “applied electric field processing” is meant to be limited to any particular type of technique or set of techniques, and is not meant to be limited to currently used or known techniques. It is noted that some applied electric field techniques may also be membrane-based solution processing techniques, but this is not a requirement.

[0217] It is also noted that certain of the reverse osmosis pump/pressure letdown configurations, may be avoided, when an applied electric field is used to provide the motivating force for solution processing, rather than pressure differential. This may be advantageous in some systems. It is noted that the equipment configurations described, will be modified potentially to avoid certain pumps in the system, if applied electric field processing is used as an alternate to some or all membrane-based processing.

[0218] Reverse osmosis functions by separating water from the ions and other contaminants in the solution to be process via pressurizing the entire fluid volume. Applied electric field processing functions by moving the ions in the solution via an applied electric field in combination with ion selective membranes. Thus, the work is being done on moving the ions themselves rather than pressurizing the entire feed stream may be a more efficient means of purifying the solution as part of the overall refrigeration cycle.

[0219] For an example of desirable application of the applied electric field processing, consider that in some instances, in which lithium bromide (LiBr) is used as the solute, osmotic pressures at relatively high concentrations of lithium bromide may be higher than practical for a reverse osmosis processing system, or at high concentration lithium bromide (LiBr) crystallization may limit the ability to use a reverse osmosis processing system. These factors could inhibit functionality, increase efficiency or increase cost of the reverse osmosis processing only system to an undesirable level. However, with electrodialysis techniques, higher concentrated lithium bromide solutions can be processed, at least in a stage of the processing where relatively high concentration solutions (LiBr) are involved. As the LiBr concentration is reduced, in a cascading system, one can switch to a reverse osmosis processing technique, for further processing.

[0220] It is noted that applied electric field processing can be used in any of the non-vaporizing solution processing stages, units, or systems previously described, in connection with the figures, whether used alone or in conjunction with membrane-based processing.

B. Electrodialysis Techniques

[0221] Electrodialysis (ED) it a process whereby salt ions are separated from a feed solution through the use of ion-exchange membranes and an applied electric field. The applied electric field is typically direct current. The electric field is applied across what is known as an electrodialysis stack. The stack is typically multiple alternating layers of charged or ion selective membranes. As the solution to be processed enters the stack it travels in parallel to the membranes that comprise the electrodialysis stack and perpendicular to the applied electric field. Both negatively and positively charged ions will exist in the feed solution. The negatively charged ions or anions will be attracted towards the positive side of the applied electric field (which contains a anode), while at the same time the positively charged ions or cations will be attracted towards the negative side of the applied electric field (which contains a cathode). This attraction will cause a migration of the positively charged ions and the negatively charged ions in opposite directions from each other, thus creating an electric current. These ions will then pass through an ion charge selective membrane. On one side of the feed stream the positive ions will migrate through the negatively charged selective membrane into a concentrated ion stream, while at the same time the negative ions will migrate through a positively charged selective membrane on the opposite side of the feed stream. As the ions continue to move through the concentrated ion stream towards the anode
or cathode they will encounter an alternatively selective membrane. This alternatively selective membrane will be positively charged on the concentrated stream side containing the separated cations and negatively charged on the concentrated stream side containing the separated anions thus repulsing the likely charged ions away from this second membrane an inhibiting further ion progress in the direction of the applied electric field.

[0222] In the case of a Lithium Bromide solution the Lithium ions will be positively charged and will migrate towards the cathode and the Bromide ions will be negatively charged and will migrate towards the anode.

[0223] An example applied electric field processing (electrodialysis processing) system is shown in FIG. 7. Here the lines 701 represent positively charged ion selective membranes and lines 702 represent the negatively charged ion selective membranes. That is, at least selected positive ions do not readily pass through membrane 701, and at least selected negative ions do not readily pass through membrane 702. There may be many streams to be purified (reduced in ion concentration) which are illustrated here as input streams 705, and the streams which are correspondingly to be increased in selected ion concentration are shown here as streams 706. The reduced-solute solvent product (off) streams are shown at 707, and the concentrated off-streams are shown at 708. In an example, near the anode (710) and cathode (711) there may be some electrolysis of water into H₂ and O₂. Near the anode 710 the hydrogen ions H⁺ ions which may pair with the negative (for example Bromide) ions to form a hydrogen bromide salt which, when in solution, forms hydrobromic acid (a low pH solution), while near the cathode 711 the OH⁻ ions will form and pair to balance charge with the positive (for example Li⁺ ions) to produce, for example, a Lithium Hydroxide solution which is a basic solution.

[0224] In general terms, the designator “X⁻” indicates a cationic solute species, for example Li⁺ or Na⁺. The term “Y⁺” designates an anionic solute species, for example Cl⁻ or Br⁻. The term “Z⁻” indicates another solute species, for example SO₄⁻².

[0225] The schematic indicates preferential passage of various solute species through certain membranes over others, to generate the identified flow lines out from the system, from various introductory liquids into the system.

[0226] Numerous companies produce materials usable for ion exchange (or ion selective) membranes. These include: Lenntech BV, Rotterdamseweg 402, M2629 HH Delft, Netherlands; Dow Chemical Company, 2030 Dow Center, Midland, Mich. 48674; and, General Electric Co., 3135 Easton Turnpike, Fairfield, Conn. 06828-0001.

C. Electrodeionization Techniques

[0227] Electrodeionization (EDI) is similar to ED in regards to the applied electric field via an anode and cathode and with regards to the positively and negatively charged ion selective membrane arrangements, although arrangements can vary. The primary difference between these two technologies is the use of an ion exchange resin. In EDI the purifying compartment (or flow streams) and sometimes the concentrating compartments (or flow streams) contain an ion exchange resin. In traditional deionization processes the stream to be processed is passed through an ion exchange resin which preferentially binds to undesirable ions in the water and replaces them less harmful ions. As this process occurs the resin becomes saturated with the ions being removed from the feed stream and depleted of its replacement “exchange” ions. Once this occurs the resin need to be regenerated to flush out the undesirable ions. This is typically done with acid and caustic solutions. In the EDI system the OH⁻ ions that form produce the caustic action necessary to continuously regenerate the ion exchange resin, while at the same time the H⁺ ions that from under the influence of the anode will produce an acidic solution that also regenerates the resin on a continuous basis.

D. Capacitive Deionization

[0228] Capacitive deionization (CDI), sometimes called electrosorption desalination, is a technology for desalination and water treatment in which salts and minerals are removed from water by applying an electric field between two porous (often, carbon) electrodes, similar to electric double-layer capacitors. Counterions are stored in the electrical double layers which form at the solution/matrix interface inside the porous electrodes, with the ions of positive charge (cations) stored in the negatively charged electrode, and vice-versa for the anions, which are stored in the positively biased electrode (anode).

[0229] The electrodes used in CDI are typically prepared from porous carbon particles with internal areas for ion adsorption in the order of 1000 m² per gram, but other materials are also possible, such as carbon nanotubes and nanofibers. The two oppositely placed (planar) electrodes are separated by a thin open structured “spacers”, or flow channel, through which the water flows. Upon applying an electrical potential difference between the two electrodes of the order of 0.8-1.5 V, anions are adsorbed in the anode and cations into the cathode, thereby producing a (partially) ion-depleted product stream. After the ion adsorption capacity of the electrodes has been reached, the applied voltage difference can be reduced to zero and a small product stream concentrated ions is obtained in the ion release-step. In this way, for example, an inflowing stream of brackish water is split into a partially deionized stream and a more concentrated brine.

E. Membrane Capacitive Deionization

[0230] Membrane capacitive deionization (MCDI), sometimes called “flow-through capacitor technology”, is a modification of CDI by inserting an anion-exchange membrane in front of the anode, and a cation exchange membrane in front of the cathode. In this way, the ions of equal charge sign as the electrode, the so-called co-ions (e.g., the anions in the cathode) are inhibited from leaving the electrode region. This co-ion-exclusion-effect, which at low voltages negatively influences the salt adsorption rate and removal capacity in CDI, is absent in MCDI. Another advantage of MCDI is that during ion release, it is possible to use a reversed voltage which leads to a faster and more complete rejection of the counterions back into the flow channel.

F. Some General Observations

[0231] Applied Electric Filed Processing can be used in place of, or in concert with, membrane-based processing such as reverse osmosis processing. For example, in some instances the use of applied electric field processing may be a preferred technology where the salt solution is strongest, from the absorber, and reverse osmosis or a cascading reverse
osmosis arrangement could be used where concentrations of the solution are lower. In some systems the opposite may be preferred.

IX. Some Additional Comments

A. High Charge Density Solid Electrolyte or Polyelectrolyte Membrane

[0232] It is possible that one could use a solid electrolyte membrane, polyelectrolyte membrane, or a nano-structured solid polymer membrane to serve as a separation membrane as a method of accomplishing the desired solution processing. Such a membrane of can be obtained from Dais Analytic Corporation, 11552 Prosperous Drive, Odessa, Fla. 33556.

[0233] This type of membrane could be used to process high concentrationionic solutions in a manner that utilizes a vaporization step between the purified solvent side surface of the membrane and another surface where the permeate could be condensed upon, and collected from.

B. Battery Regeneration

[0234] If an applied electric field processing technique is utilized there would likely be a separation of ionic species by ionic electric charge. These separated streams of concentrated ionic charge (electrolytes) could then be re-introduced to each other via a "reverse" applied electric field processing step, whereby electric power could be generated and therefore recovered. Reversed Electro Dialysis (RED) or Flow Batteries are examples of just such a process.

[0235] This recovered electrical energy can be utilized to offset the power consumption of other portions of the cycle thereby reducing the overall net energy requirement of the cycle.

[0236] It is further recognized that the separated ionic species electrolytes could be generated and collected into storage vessels and then recombined through an electrical energy generating process at a later time as a means of managing electrical power consumption profiles over time.

C. Concentrated Brine Storage

[0237] Because the useful cooling in the refrigeration cycle is being provided in part by the introduction of a strong solution into the absorber where that strong solution is then diluted via the absorption of refrigerant vapor that is received from the evaporator; it is recognized that a user of this cycle could produce and store a strong solution and store that strong solution for later use as a means of either providing an emergency backup reserve of cooling in the event of a loss of primary power, or could use the stored strong solution to produce cooling with a significantly reduced power consumption requirement during specific time periods as a means of managing electrical power consumption profiles over time.

D. Characterization of Techniques and Systems that have Some Level of Refrigerant Vaporization/Recondensation During Processing

[0238] Herein above, preferred techniques are characterized for "non-vaporizing" or "non-phase change" systems, with respect to refrigerant recovery. That is, the techniques are characterized as usable in processes and techniques in which recovery of the refrigerant from the dilute solution is conducted without a phase change, i.e., without a vaporization/recondensation of the refrigerant. Numerous techniques applicable to accomplish this were described.

[0239] It is noted that many of the techniques of the present disclosure can be applied in systems in which there is at least some form or some amount of refrigerant vaporization also occurring, during processing of dilute solution to recover refrigerant liquid. For example, a membrane-based technique can be applied in which there is some vaporization. Indeed, in Section IX. A. above, the type of membrane characterized has been described as including a form of vaporization step between layers of the membrane.

[0240] In general, techniques according to the present disclosure, can be applied in a process of conducting an absorption refrigeration cycle, or in an absorption refrigeration cycle, in which dilute solution is processed into concentrated solute solution and refrigerant liquid with: a membrane-based solution processing step and equipment, and/or an applied electric field processing or step, without regard to whether there is also a step of vaporizing and condensing refrigerant; with additional steps of directing at least a portion of the refrigerant liquid into a first evaporator arrangement to vaporize at least a portion of the refrigerant; directing the concentrated solute solution into an absorber arrangement; and, directing vaporized refrigeration from the evaporator arrangement into an absorber arrangement, for absorption of the refrigerant concentrated solute solution therein. Indeed, an absorption refrigeration cycle can be provided which includes: at least a first absorber arrangement configured to absorb refrigerant gas, from a first evaporator arrangement, into a solution to provide a dilute solution; at least a first evaporator arrangement configured to receive refrigerant liquid and to process at least a portion of the refrigerant into refrigerant gas; and, a solution processing unit system configured to process dilute solution into: strong solution; and, refrigerant liquid, at least a portion of which refrigerant liquid is for direction to the first evaporator arrangement, and wherein the solution processing unit system, includes at least: a membrane-based processing unit system; an applied electric field processing unit system; and/or both, without regard to whether there is also a step of vaporizing done, i.e., without regard to whether the solution processing system is completely "non-vaporizing" or "non-phase change."

[0241] In general, the particular combination of technique chosen, for a given system will turn on availability of energy and energy costs, as well as the characteristics of the solution.

X. Summary of General Principles and Techniques

[0242] According to the present disclosure, techniques, methods, and equipment usable for absorption refrigeration cycle processing, are described. The techniques can be applied in a wide variety of absorption refrigeration cycles, as indicated generally above. However, a typical characteristic of many absorption refrigeration cycle in which techniques according to the present disclosure are used, is that solution from an absorber arrangement, comprising dilute absorptive solution (typically a strong solute/solvent combination or strong solution, having absorbed therein refrigerant) is processed to recover the refrigerant without vaporizing (boiling) refrigerant, i.e. without phase change. Typically, this is accomplished by processing of the dilute absorptive or absorber solution by non-vaporizing (or non-phase change) solution processing.

[0243] Herein, two general types of solution processing are described. These types are "membrane-based processing" and "applied electric field processing." The terms are not meant, however, to be fully mutually exclusive. For example,
some “membrane-based solution processing” may also be “applied electric field processing.” Also, when a system is characterized as “comprising membrane-based solution processing”, it is not meant to indicate that the system does not also include “applied electric field processing” whether that “applied electric field processing” is also membrane-based processing. Further, if the system or technique is characterized as “comprising applied electric field processing” it is not meant that the system does not include “membrane-based processing” whether that “membrane-based processing” involves an applied electric field.

The term “membrane-based processing” and variants thereof, as used herein, is meant to refer to any non solution processing in which a membrane is used to provide for selective transfer of solute/solvent, as part of a processing to generate a more dilute (i.e. purified) solvent and a more concentrated (in solute) solution. The term “applied electric field solution processing” is used to refer to any non solution processing in which an applied electric field is used to facilitate solute or selected solute removal from solution, to facilitate a recovery of refrigerant and/or concentrated solution.

It is noted that in techniques according to the present disclosure, various forms of solution processing can be used in the same system or process.

An example membrane-based processing technique referenced herein is “reverse osmosis processing.” The term “reverse osmosis processing” as used herein in this context, is meant to be a broad, non-equivalent specific and non-configuration specific term, that indicates processing by using a reverse osmosis membrane arrangement to pass a selected solvent or solvent system through the membrane arrangement, from a high pressure side to a low pressure side, while concentrating solute at the high pressure side. This can be used to recover refrigerant as a purified solvent, and to regenerate a diluted solution into a concentrated solute solution (i.e. absorber solution).

The term “applied electric field processing” as used herein in the context is meant to be broad, non-equivalent specific and non-configuration specific term that indicates processing by using equipment in which an applied electric field is used to generate a motivating force for transfer of a solute or selected solute material from a solution. Some examples of “applied electric field processing”, includes electrodialysis; electrodemontization; capacitive deionization; and, membrane capacitive deionization techniques, each of which can be applied in systems according to the present disclosure.

In many typical applications of the techniques described herein, the “membrane-based processing” and/or “applied electric field processing” techniques applied will be non-vaporizing or non-phase change solution processing, i.e. conducted without vaporization of refrigerant (in follow-up with condensation) for refrigerant recovery. Indeed, in typical applications, the entire solution processing system and steps involved (for refrigerant liquid recovery) will be a “non-vaporizing solution processing system” although alternatives are possible.

Typically, then, the refrigeration cycle is operated to lead to recovery of the refrigerant in liquid form, without requiring the refrigerant to be boiled (vaporized) out of the dilute solution, and then condensed for recovery in liquid form. Thus, equipment in a typical prior art absorption cycle for conducting these steps can be avoided to advantage.

Although alternatives are possible, in many typical absorption refrigeration cycles according to the present disclosure, then, the following are included:

a) at least a first absorber arrangement configured to absorb refrigerant vapor into a strong solution, providing a dilute solution;

b) at least a first evaporator arrangement configured to receive at least a portion of the refrigerant liquid and to process at least a portion of the refrigerant liquid into a refrigerant gas; and,

c) a non-vaporizing processing unit system configured to process the dilute solution into: strong solution for direction to an absorber arrangement (with or without further processing); and, a refrigerant liquid, at least a portion of which is for use in the refrigeration cycle (with our without further processing).

The “non-vaporizing” processing unit system can be a membrane-based processing system, an applied electric field processing system, an alternate processing system, or a system using a combination of such techniques, as characterized herein. An example membrane-based processing system and technique characterized as usable, is a reverse osmosis processing. Examples of applied electric field processes comprise: electrodialysis; electrodemontization; capacitive deionization; and, membrane capacitive deionization. It is again noted that the terms “applied electric field processing” and “membrane-based processing” are not meant to be necessarily exclusive.

Herein, when it is said that the strong solution is directed into an absorber arrangement (with or without further processing), reference is meant to alternatives such as suggested by the examples of FIGS. 3 and 4-6. In FIG. 3, for example, the specific configuration depicted shows strong solution at line 85 from a non-vaporizing solution processing unit system being shown directed directly into absorber arrangement 83, i.e. without further processing. A similar characterization applies for FIG. 4, although at joint 432 the dilute solution is split into two lines, one for each of two absorber arrangements, or portions of an overall absorber arrangement. In FIG. 5, from joint 532 a portion of strong solution from processing unit system 82 is directed into absorber arrangement 83. However, another portion via line 540 is directed to processing unit system 82b for further processing. On the other hand, strong solution at line 550 from processing unit system 82b is directed into unit 420 without further processing.

Finally, in the example of FIG. 6, strong solution at line 85 from processing unit system 82 is split at joint 620, with a portion directed in line 630 for further processing at processing unit system 820 before being directed via line 640 and ultimately line 652 into absorber arrangement 420. Further, additional processing can be characterized as occurring within unit 420 before the solution via line 611 is directed into absorber arrangement 83.

The term “reverse osmosis processing” is used herein, is also meant to be general, and non-specific, with respect to particular equipment configurations. One or more membrane arrangements can be used and varied configurations (including a variety of membrane arrangements, pump arrangements, line arrangements, pressure let-down devices, etc.) can be used. The term “reverse osmosis processing,” in general, is merely meant to indicate a processing step in
which a separation is conducted by use of a reverse osmosis membrane arrangement with a pressure differential thereacross.

[0258] Typically, a reverse osmosis (membrane) unit system includes at least one (and typically a plurality) reverse osmosis membrane unit having: a high pressure side inlet; a high pressure side outlet; a low pressure side inlet; and, a low pressure side outlet. However, the system may also include at least one reverse osmosis membrane unit having: a high pressure side inlet; a high pressure side outlet; a low pressure side inlet; and, a low pressure side outlet. Many systems will include at least one of each.

[0259] In general terms, for the reverse osmosis (membrane) unit system and reverse osmosis processing, equipment, techniques and methods described generally in U.S. application Ser. No. 12/455,998, filed Jun. 9, 2009 and U.S. provisional 61/131,947, filed Jun. 13, 2008, each of which is incorporated herein by reference, can be used.

[0260] When such techniques are applied, although alternatives are possible, typically the reverse osmosis processing comprises steps of:

(a) providing a cascading reverse osmosis system including at least:

(i) a first, final, solvent outlet-generating reverse osmosis unit;

(ii) an intermediate reverse osmosis (membrane) unit system comprising at least one reverse osmosis unit;

and,

(b) operating the reverse osmosis system to process the dilute solution such that:

(i) concentrate from the first, final, solvent outlet-generating reverse osmosis unit is directed into the intermediate reverse osmosis membrane unit system, as part of a feed stream thereto;

(ii) reduced-solute solvent from the intermediate reverse osmosis membrane unit system is directed into the first, final, solvent outlet-generating reverse osmosis unit as part of an inlet feed stream thereto;

(iii) concentrate from the intermediate reverse osmosis membrane unit system is directed into a first, final, concentrate outlet-generating reverse osmosis unit as part of an inlet feed stream thereto;

(iv) each reverse osmosis unit in the intermediate reverse osmosis membrane unit system is conducted with both a high pressure side inlet feed and a low pressure side inlet feed;

(v) each reverse osmosis unit of the intermediate reverse osmosis membrane unit system provides a high pressure side concentrate outlet and a low pressure side outlet; and,

(vi) the dilute solution to be processed is directed to at least one of the: first, final, solvent outlet-generating reverse osmosis unit; the intermediate reverse osmosis (membrane) unit system; or, the first, final, concentrate outlet-generating reverse osmosis unit.

[0272] In some instances, portions of the above can be avoided.

[0273] Examples of such arrangements are described herein in connection with FIGS. 3A, and 3B. For the reverse osmosis unit system characterized in FIG. 3A: the first, final, solvent outlet-generating reverse osmosis unit is unit F; the intermediate reverse osmosis membrane unit system comprises reverse osmosis units G, F, E, D, C, and B; and, the first, final, concentrate outlet-generating reverse osmosis unit is unit A. In the example of FIG. 3B, the first, final, solvent outlet-generating reverse osmosis unit is unit R; the intermediate reverse osmosis membrane unit system comprises units Q, P, O, N, and M; and, the first, final, concentrate outlet-generating reverse osmosis unit is unit L.

[0274] It is noted that with respect to the system depicted in FIG. 3A, reverse osmosis unit B will sometimes be referred to as the final, concentrate flow direction, reverse osmosis unit, for the intermediate reverse osmosis membrane system comprising units B, C, D, E, F and G; and, unit G will sometimes be referred to as the final, dilute solution flow direction reverse osmosis unit of the intermediate reverse osmosis membrane unit system comprising units B, C, D, E, F and G. In an alternate statement, unit B can be characterized as the first dilute solution flow direction reverse osmosis membrane unit of the intermediate reverse osmosis membrane unit system comprising units B, C, D, E, F and G; and, unit G can be characterized as the first, concentrate, flow direction reverse osmosis unit of the intermediate reverse osmosis membrane unit system comprising units B, C, D, E, F and G.

[0275] With respect to FIG. 3B, reverse osmosis unit M can be characterized as the final, concentrate, flow direction unit (or first, dilute solution, flow direction unit) of the reverse osmosis membrane unit system comprising units M, N, O, P, and Q; and, reverse osmosis unit Q can be characterized as the final, dilute solution flow direction unit (or first, concentrate, flow direction unit) of the intermediate reverse osmosis membrane unit system comprising units M, N, O, P, and Q.

[0276] It is expected that in a typical process, each reverse osmosis unit in the intermediate reverse osmosis membrane unit system will be operated with solute concentration in the high pressure side inlet feed thereto to be within 20% of the solute concentration in the low pressure side inlet feed thereto, typically within 15% and often within 10%, although alternatives are possible.

[0277] In the general terms characterized herein, then, a process for conducting an absorption refrigeration cycle is provided. The process includes steps for processing a dilute solution into a concentrated solution and refrigerant liquid, without a step of vaporizing and condensing the refrigerant. The step of processing typically comprises directing dilute solution to a reverse osmosis unit for reverse osmosis unit system for reverse osmosis processing.

[0278] In a typical step of conducting an absorption refrigeration cycle, refrigerant liquid is directed to a (first) evaporator arrangement; concentrated solution (absorber solution) is directed into an absorber arrangement; and, vaporized refrigerant from a (first) evaporator arrangement is directed into an absorber arrangement to generate dilute solution, upon absorption by a concentrated solution in the absorber arrangement.

[0279] As indicated above, many of the techniques described herein can be applied in systems in which the solution processing, of the dilute solution into refrigerant liquid and strong solution, is conducted with some vaporization of refrigerant liquid; i.e. in which the processing is not “non-vaporizing” or “non-phase change”, as the terms used herein. Some such systems can still advantageously include (comprise) membrane-based processing and/or applied electric field processing techniques as described.

[0280] A variety of system configurations, processing techniques, refrigerants, solvents, and solutions can be applied. In
the example description provided, the dilute solution comprises an aqueous solution of lithium bromide, and the refrigerant comprises water.

It is noted that principles according to the present disclosure can be provided in a wide variety of systems, and there is no requirement that a process technique or system include each of the features characterized herein, in order to obtain some benefit according to the present disclosure.

What is claimed:
1. A process of conducting an absorption refrigeration cycle, the process comprising steps of:
   (a) processing dilute solution into concentrated solute solution and refrigerant liquid without a step of vaporizing and condensing refrigerant contained in the dilute solution;
   (b) directing at least a portion the refrigerant liquid into a first evaporator arrangement to vaporize at least a portion of the refrigerant;
   (c) directing the concentrated solute solution into an absorber arrangement;
   (d) directing vaporized refrigerant from an evaporator arrangement into an absorber arrangement, for absorption of the refrigerant into concentrated solute solution therein.
2. A process according to claim 1 wherein:
   (a) the step of processing dilute solution comprises applied electric field processing.
3. A process according to claim 2 wherein:
   (a) the step of processing dilute solution comprises at least one of electrodialysis; electrodeionization; capacitive deionization; and, membrane capacitive deionization.
4. A process according to claim 1 wherein:
   (a) the step of processing dilute solution comprises membrane-based processing.
5. A process according to claim 4 wherein:
   (a) the step of processing dilute solution comprises reverse osmosis processing.
6. A process of conducting an absorption refrigeration cycle in accord claim 1 wherein:
   (a) the step of directing the refrigerant liquid, from the step of processing, comprises directing the refrigerant liquid into the first evaporator arrangement without further dilution of the refrigerant liquid.
7. A process according to claim 6 wherein:
   (a) the step of directing the concentrated solution into an absorption arrangement comprises directing concentrated solution from a membrane-based processing step into an absorber arrangement without further concentration.
8. A process according to claim 1 wherein:
   (a) the step of directing vaporized refrigerant comprises directing the refrigerant into the absorber arrangement into which the concentrated solute solution is directed.
9. A process according to claim 8 wherein:
   (a) the step of directing concentrated solute solution into an absorber arrangement comprises directing concentrated solute solution, from the step of processing dilute solution, into the absorber arrangement into which the vaporized refrigerant is directed.
10. A process according to claim 9 wherein:
    (a) not all of the concentrated solute solution, from the step of processing dilute solution, is directed into the absorber arrangement in which the vaporized refrigerant is directed.
11. A process according to claim 1 wherein:
    (a) the step of processing dilute solution comprises a combination of membrane-based processing and applied electric field processing.
12. An absorption refrigeration cycle comprising:
    (a) at least a first absorber arrangement configured to absorb refrigerant gas, from a first evaporator arrangement, into a solution to provide a dilute solution;
    (b) a least a first evaporator arrangement configured to receive refrigerant liquid and to process at least a portion of the refrigerant liquid into refrigerant gas; and,
    (c) a non-vaporizing solution processing unit system configured to process dilute solution into: strong solution; and, refrigerant liquid, at least a portion of which refrigerant liquid is for direction to the first evaporator arrangement.
13. An absorption refrigeration cycle according to claim 12 wherein:
    (a) the non-vaporizing solution processing unit system comprises at least an applied electric field processing unit system.
14. An absorption refrigeration cycle according to claim 12 wherein:
    (a) the non-vaporizing solution processing unit system comprises at a membrane-based solution processing unit system.
15. An absorption refrigeration cycle according to claim 14 wherein:
    (a) the membrane-based solution processing unit system includes at least one reverse osmosis unit having: a high pressure side inlet; a high pressure side outlet; a low pressure side inlet; and, a low pressure side outlet.
16. An absorption refrigeration cycle according to claim 12 wherein:
    (a) the first absorber arrangement is configured to absorb refrigerant gas into strong solution, to provide dilute solution.
17. An absorption refrigeration cycle according to claim 12 wherein:
    (a) the non-vaporizing solution processing unit system is configured to process the dilute solution from the absorber arrangement into: the strong solution; and, a refrigerant liquid for direction to the first evaporator.
18. An absorption refrigeration cycle according claim 12 wherein:
    (a) the non-vaporizing solution processing unit system includes both an applied electric field solution processing unit system and a membrane-based processing unit system.
19. A process of conducting an absorption refrigeration cycle; the process comprising steps of:
    (a) processing dilute solution into concentrated solute solution and refrigerant liquid by at least one of membrane-based processing and applied electric field processing;
    (b) directing at least a portion the refrigerant liquid into a first evaporator arrangement to vaporize at least a portion of the refrigerant;
    (c) directing the concentrated solute solution into an absorber arrangement; and,
    (d) directing vaporized refrigerant from an evaporator arrangement into an absorber arrangement, for absorp-
tion of the refrigerant into concentrated solute solution therein.

20. An absorption refrigeration cycle comprising:
   (a) at least a first absorber arrangement configured to absorb refrigerant gas, from a first evaporator arrangement, into a solution to provide a dilute solution;
   (b) at least a first evaporator arrangement configured to receive refrigerant liquid and to process at least a portion of the refrigerant liquid into refrigerant gas; and,

(c) a processing unit system configured to process dilute solution into: strong solution; and, refrigerant liquid, at least a portion of which refrigerant liquid is for direction to the first evaporator arrangement; the solution processing unit system comprising at least one of: a membrane-based processing unit system; and, an applied electric field processing unit system.

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