ABSTRACT
An apparatus and method for condensing water vapor in air to extract liquid water in which a refrigeration system defines a closed-loop refrigerant path. The refrigeration system includes a main portion, a first branch portion and a second branch portion. The first branch portion and the second branch portion each have an entrance and an exit in fluid communication with the main portion. The first branch portion includes a first evaporator operable at a temperature of at least a dew point of air contacting the first evaporator to cause liquid water to condense on an exterior surface of the first evaporator. The second branch portion includes a second evaporator. A first water vessel is positioned proximate to the first evaporator for collecting water from the exterior surface of the first evaporator. A second water vessel is positioned proximate to the second evaporator for holding water chilled by the second evaporator. A conduit transports water from the first water vessel to the second water vessel.
FIG. 10

PRIOR ART
1 to 2 = Compression of Vapor
2 to 3 = Vapor superheat removed in condenser
3 to 4 = Vapor converted to liquid in condenser
4 to 5 = Liquid flashes into liquid + vapor across expansion valve
5 to 1 = Liquid + vapor converted to all vapor in evaporator

**FIG. 11**

PRIOR ART
**TYPICAL SINGLE-STAGE VAPOR COMPRESSION REFRIGERATION**

**FIG. 12**
WATER PRODUCTION SYSTEM AND METHOD WITH AUXILIARY REFRIGERATION CYCLE

CROSS-REFERENCE TO RELATED APPLICATION


STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

FIELD OF THE INVENTION

[0003] The present invention relates generally to production of water, and more specifically to improved systems and methods for extracting water from water vapor, for example from the atmosphere.

BACKGROUND OF THE INVENTION

[0004] Ambient air naturally contains some quantity of water vapor, so the general atmosphere is a potential water source. Extracting this water from the surrounding atmosphere presents several challenges. Other attempts to produce water from atmospheric air have typically fallen short of the desirable criteria, including efficiency in the amount of water produced per the amount of energy used, extracting the greatest possible percent of the moisture available in the air under local conditions, and producing acceptable quantities of water at all times of day and in various weather, seasons, and climates. Therefore, atmospheric water vapor is an essentially untapped source of greatly needed water supplies that is potentially available worldwide.

[0005] Refrigeration systems have been known for some time. Vapor-compression cycle refrigeration systems are most common today, but other types of refrigeration are possible including gas absorption and heat pumps. A refrigeration system may provide one or more closed-loop circuits for a refrigerant medium. If the refrigeration system uses a vapor-compression cycle, it may include a compressor, evaporator, expansion valve, and condenser.

[0006] Diagrams of an example vapor compression refrigeration system, and its thermodynamic operation, are shown in FIGS. 10-12. For example, a compressor may compress a refrigerant from a saturated vapor state to a superheated vapor state. A condenser may then remove the superheated condition from the refrigerant vapor, and then condense the refrigerant to a saturated liquid state. Across an expansion valve, the refrigerant may become mixed states of liquid and vapor. And an evaporator may convert the refrigerant back to saturated vapor. During this cyclical process, an external surface of the evaporator will become cold. Some form or variation of this process may be used in refrigerators, freezers, and air conditioning systems.

[0007] Most refrigeration systems have some cooling element, through which air passes to shed heat and reach a lower temperature. In a vapor compression cycle refrigeration system, the cooling surface of the cooling element will be an exterior surface of the evaporator. An evaporator having a temperature of at most a dew point of air contacting the evaporator will cause liquid water to condense on an exterior surface of the evaporator.

[0008] Whenever this cooling element has a temperature at or less than the local dew point of the air, water vapor in the air will tend to condense into droplets of liquid water. When a cooling element has a temperature at or less than the freezing point of water, such as in a freezer, water vapor in the air will tend to condense and then freeze into ice.

[0009] In most residential and commercial refrigeration systems, this condensation is considered undesirable, and some refrigeration systems even have features for ameliorating them. However, the principles causing such condensation can be used to produce liquid water from water vapor in atmospheric air.


[0011] These patented methods and devices present viable means of extracting liquid water from atmospheric air, including apparatus for transforming atmospheric water vapor into potable water, and particularly for obtaining drinkable quality water through the formation of condensed water vapor on surfaces maintained at a temperature at or below the dew point for a given ambient condition. The surfaces upon which the water vapor is condensed are kept below the dew point by a refrigerant medium circulating through a closed fluid path, which includes refrigerant evaporation apparatus, thereby providing cooling of air flowing through the device, and refrigerant condensing apparatus to complete the refrigeration cycle.

[0012] Water production systems also suffer from the drawback in which the refrigeration system operates in an “all or nothing” manner such that trying to keep the produced water cool also results in the extraction of additional water from the atmosphere. The result is that operation of the compressor for a system whose water collection vessel is full will result in overflow of the vessel or that the system cannot be operated to keep the collected water cool. Neither is a desirable result or situation.

[0013] It is desirable to provide a water production system with different operating modes, to customize operation of the water production system and its refrigeration system.

SUMMARY OF THE INVENTION

[0014] The present invention advantageously provides a system, device and method for extracting water from air using a refrigeration system having different operating modes for customized operation of the water production system and the refrigeration system.

[0015] In accordance with one aspect, the present invention provides an apparatus for extracting water from air in which a refrigeration system defines a closed-loop refrigerant path. The refrigeration system includes a main portion, a first branch portion and a second branch portion. The first branch portion and the second branch portion each have an entrance and an exit in fluid communication with the main portion. The first branch portion includes a first evaporator operable at a
temperature of at most a dew point of air contacting the first evaporator to cause liquid water to condense on an exterior surface of the first evaporator. The second branch portion includes a second evaporator. A first water vessel is positioned proximate to the first evaporator for collecting water from the exterior surface of the first evaporator. A second water vessel is positioned proximate to the second evaporator for holding water chilled by the second evaporator. A conduit transports water from the first water vessel to the second water vessel. In accordance with another aspect, the present invention provides a method of extracting water from air.

In accordance with another aspect, the present invention provides a method of extracting water from air using a water production system in which the water production system includes an air movement device, a first water vessel, a second water vessel and a refrigeration system having a first cooling element and a second cooling element. The air movement device is operated to cause air to flow and contact the first cooling element. The refrigeration system is operated to cause the first cooling element to have a temperature of at most a dew point of air contacting the first cooling element during operation and to cause the second cooling element to have a temperature less than the temperature of a fluid contacting the second cooling element during operation. Liquid water is condensed from the air on an exterior surface of the first cooling element. The water is collected in the first water vessel. A portion of the water is moved from the first water vessel into the second water vessel. The water in the second water vessel is cooled using the second cooling element. The air movement device is shut off if an amount of water in the first water vessel exceeds a predetermined amount.

In accordance with still another aspect, the present invention provides a method of extracting water from air using a water production system in which the water production system includes an air movement device, a first water vessel, a second water vessel and a refrigeration system having a first cooling element and a second cooling element. An amount of water in the first water vessel is monitored, and a temperature of water in the second water vessel is monitored. The air movement device is operated to cause air to flow and contact the first cooling element when the amount of water in at least one of the first water vessel and the second water vessel is below a predetermined amount. The refrigeration system is operated to cause the first cooling element to operate at a temperature of at most a dew point of air contacting the first cooling element and to cause the second cooling element to refrigerate the second water vessel. Liquid water is condensed from the air on an exterior surface of the first cooling element. The water is collected in the first water vessel. A portion of the water is moved from the first water vessel into the second water vessel when the amount of water in the first water vessel exceeds a predetermined amount.

A more complete understanding of the present invention, and its associated advantages and features, will be more readily understood by reference to the following description and claims, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention, and the attendant advantages and features thereof, will be more readily understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a diagrammatic side view of an exemplary water production system, constructed in accordance with the principles of the present invention;
FIG. 2 is a diagrammatic side view of an exemplary water production system, constructed in accordance with the principles of the present invention;
FIG. 3 is a diagrammatic side view of an exemplary water production system, constructed in accordance with the principles of the present invention;
FIG. 4 is a partial perspective view of an exemplary water production system constructed in accordance with the principles of the present invention;
FIG. 5 is a partial perspective view of an exemplary water production system constructed in accordance with the principles of the present invention;
FIG. 6 is a diagrammatic top view of the exemplary water production system of FIG. 4;
FIG. 7 is a diagrammatic side view of the exemplary water production system of FIG. 4;
FIG. 8 is a partial exploded view of refrigeration system components of an exemplary water production system, constructed in accordance with the principles of the present invention;
FIG. 9 is a partial exploded view of refrigeration and structural components of an exemplary water production system, constructed in accordance with the principles of the present invention;
FIG. 10 is a psychrometric chart of water, showing the physical properties of moist air at sea level;
FIG. 11 is a representative diagram of temperature and entropy for an exemplary refrigerant; and
FIG. 12 is a representative diagram of a known refrigeration system.

DETAILED DESCRIPTION OF THE INVENTION

The present invention advantageously provides an improved system and method for extracting water from water vapor, for example from the atmosphere. The water production system of the present invention may have various sizes, arrangements and features.

Some aspects of the present invention relate to combinations of components and method steps for implementing systems and methods to improve the efficiency and operation of water production systems. Accordingly, some components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention, so as to avoid details that will be readily apparent to those of ordinary skill in the art having the benefit of this description.

Relational terms, such as “first” and “second,” “top” and “bottom,” and the like, may be used solely to distinguish one entity or element from another entity or element, without necessarily requiring or implying any physical or logical relationship or order between such entities or elements.

Referring to the drawings, various embodiments of water production devices are illustrated. The illustrations of course depict only some of many different possible designs that are within the scope of the present invention. In particular, the present invention encompasses water production systems having numerous combinations of elements, and the description of any element also contemplates providing more
than one of that element. For clarity and convenience, the present detailed description will only describe a few specific embodiments of the present invention.

[0036] An apparatus for extracting water from the water vapor in atmospheric air may generally include a refrigeration system having a cooling element and a subcooler, with a water basin for collecting water as it condenses on the cooling element, in which the subcooler is submerged. The cooling element has a temperature of at most a dew point of air contacting the cooling element, so that liquid water condenses on an exterior surface of the cooling element.

[0037] The refrigeration system may be of various types, including vapor-compression cycles, gas absorption and heat pumps. Regardless of which type of refrigeration system is chosen, the refrigeration system should have at least one cooling element, with an exterior cooling surface. During operation, the cooling surface is maintained at a temperature which is at or less than a dew point of air. In other words, atmospheric air flowing through a water production system can contact a cooling element of a refrigeration system having a temperature of at most the dew point, to cause liquid water to condense on a cooling surface.

[0038] An example water production system may include for example, a first and second cooling element, and a first and second water vessel. The first water vessel may be positioned proximate to the first cooling element for collecting water condensing on its exterior surface. The second water vessel may be positioned proximate to the second cooling element for holding water chilled by the second evaporator. A conduit may also be provided for transporting water from the first water vessel to the second water vessel. According to some of the principles of the present invention, an apparatus and method may be used to optimize water production, which may include maintaining a desired amount of chilled potable water.

[0039] With specific reference to the drawings, in which like reference designators refer to like elements, an exemplary diagram of a water production system is shown in FIG. 1, and is generally designated as “10.” In this particular illustrated example, water production system 10 has a refrigeration system 12, which may be of any suitable type, and may have various arrangements of refrigeration components. If the refrigeration system is of the vapor-compression type, it may include for example at least one compressor, evaporator, expansion valve, and condenser. The refrigeration system may provide one or more closed-loop circuits for a refrigerant medium.

[0040] In the diagram of FIG. 1 for example, a refrigeration circuit may be arranged from a compressor 20, to a first condenser 22, to a second condenser 24, to an optional subcooler 14, to an expansion valve 26, to an evaporator 28, and back to the compressor 20. A refrigerant medium may proceed in a closed-loop path around the components and conduits of the refrigeration system.

[0041] For example, a refrigerant in a saturated liquid state may cross expansion valve 26, becoming mixed states of liquid and vapor. Evaporator 28 may then convert the refrigerant back to saturated vapor. An external surface of the evaporator 28 may accordingly be cooled to a temperature at or below the local ambient dew point of air, which will tend to cause liquid water to condense from water vapor in the air. The resulting cooled liquid water will tend to condense and fall from the evaporator 28, into a water basin 16.

[0042] Continuing a refrigeration cycle description, the compressor 20 may then compress refrigerant from a saturated vapor state to a superheated vapor state. The first condenser 22 may then remove the superheated condition from the refrigerant vapor, thus acting as a de-superheater. The second condenser 24 may then condense the refrigerant to a saturated liquid state. Then, subcooler 14 of the present invention uses water in the water basin 16 to further cool the saturated liquid refrigerant. The subcooler 14 may thus serve as a reservoir for liquid refrigerant until needed, based on demand through the expansion valve.

[0043] Passing the tubing of the subcooler through water transfers heat from the refrigerant inside the subcooler by conduction, and by some water flow through the water basin into the water collection vessel, rather than merely by convection alone with the air. Also, water in the water basin will tend to have a temperature lower than the ambient air temperature, having fallen from condensation in contact with the cooler external surfaces of the evaporator. Accordingly, the water in the water basin is even more effective than ambient air, for example, to cool the refrigerant inside the subcooler.

[0044] The subcooler may have various desired arrangements, such as for example a conduit or tube having any suitable shape, including straight, curved, undulating, convoluted, sinusoidal, coiled, spiral, etc. The subcooler may also have either a two-dimensional or three-dimensional shape or pattern. If desired, a subcooler may have bends that are smooth and accurate, to facilitate flow of refrigerant through it. Also, it may be desirable to provide a convoluted shape of some kind, to maximize the external surface area of the subcooler in contact with water in the water basin. Such a larger surface area will tend to consequently maximize heat transfer from the refrigerant inside the subcooler to the water in the water basin. Accordingly, a subcooler may increase efficiency of the refrigeration system, and lower operating costs of the water production system.

[0045] The water basin may also be fitted with a mechanism for maintaining a desired amount of water in the water basin, so that the subcooler remains submerged. Such a water-level maintaining mechanism may have any suitable configuration, including a float-actuated device, servo mechanism, or the illustrated example of a rain tube 32. Drain tube 32 may be arranged vertically, with an inlet port 34 inside the water basin, at an elevation or a vertical position above the subcooler, and an outlet port 36 opening above the water collection vessel 18.

[0046] Accordingly, water basin 16 will tend to initially fill with water until the level reaches the elevation of the drain tube 32 inlet port, which is vertically positioned to completely submerge the subcooler in water. Additional water will then tend to drain into the inlet port 34, through drain tube 32, exiting from outlet port 36 and into water collection vessel 18.

[0047] As indicated by the arrows in FIG. 1, air flow may be provided to or by the water production system, passing through the refrigeration system and particularly through the evaporator and condensers. Of course, the air flow may be natural or forced, with or without an air movement device such as a fan.

[0048] Another embodiment of the present invention may provide one or more additional refrigeration systems. For example, a water production system may include more than one refrigeration system.

[0049] For example, the water production system shown in FIG. 2 provides a first and second refrigeration system, each arranged in a similar fashion and defining separate closed-
loop refrigerant paths. The two refrigeration systems include two compressors 38 and 40, two matching pairs of evaporators 58, 60, 62 and 64, two water-cooled subcoolers 50 and 52, two pairs of expansion valves 54, 55, 56, and 57, and two pairs of condensers 42, 44, 46 and 48. An air movement device such as a fan 66 may be used to cause air flow, for example in the direction of the arrows in FIG. 2.

[0050] An example cold water refrigeration circuit of a portable water collection apparatus, constructed in accordance with the principles of the present invention, is described with reference to FIG. 3. The particular embodiment shown in FIG. 3 depicts an exemplary water production system for extracting potable water from the atmosphere, including a compressor 124, a first condenser 68 and a second condenser 70, a water-cooled subcooler 72, an expansion valve 74, and one or more evaporators 76. First condenser 68 may be provided to perform the role of a de-superheater. A housing 78 may include an air inlet 80 and an optional air bypass inlet 82, into which ambient air may be pulled by way of a fan 84. The air may then be evaporated at an exit opening in the housing 78 where the fan 84 is generally positioned. The amount of bypass air introduced into the housing 78 through the air bypass inlet 82 relative to air flowing into inlet 80 may be controlled and modulated by a valve or damper 86. In one embodiment, damper 86 may be operated by a stepper motor, servo, or other controller, which in turn may be manually controlled or coupled with a microcontroller to cause the operation and adjustment of damper 86 based on environmental or other conditions.

[0051] The optional bypass inlet 82 and the associated damper 86 may be physically located between the condenser 70 and the evaporator 76. At lower temperatures, the damper may be closed, thereby allowing more air to flow over evaporator 76. At higher temperatures, the damper 86 may be opened, allowing more air over condensers 68 and 70 in comparison to the amount of air flowing over evaporator 76. Less air flowing over evaporator 76 means a lowering of the temperature of the refrigerate in evaporator 76. With damper 86 open, the needed air pressure may drop to about 8 pounds per minute, requiring less energy to operate. If the dimensions of bypass air inlet 82 are made larger relative to air inlet 80, the required air pressure may be able to be lowered to approximately 5 pounds per minute.

[0052] Air entering housing 78 through air inlet 80 passes through evaporator 76 and then de-superheater 68 or condenser 70. Evaporator 76, de-superheater 68 and condenser 70 operate as known in the art based on the flow of refrigerant through the refrigeration components. Air entering housing 78 through air bypass inlet 86 passes through de-superheater 68 or condenser 70, and bypasses evaporator 76.

[0053] The refrigerant flow of the present invention may be described as follows. Refrigerant is compressed by compressor 124 and flows through a conduit to de-superheater 68 and then condenser 70, where it collects in water-cooled subcooler 72. This portion of the refrigeration system may be referred to as a main portion. The refrigerant then flows through thermostatic expansion valve 74 and through evaporator 76. This portion of the refrigeration system may be referred to as a first branch portion. The thermostatic expansion valve 74 is controlled by temperature sensing bulb 88. Temperature sensing bulb 88 is in contact with the suction line after the evaporator 76, and measures the temperature of the refrigerant leaving evaporator 76. As the temperature of evaporator 76 increases, more refrigerant is needed to effect the extraction of the water from the air by maintaining or lowering the surface temperature of the evaporator 76. As the temperature of the refrigerant exiting evaporator 76 increases, the pressure in temperature sensing bulb 88 increases, thereby exerting pressure on a diaphragm inside the expansion valve 74, which in turn allows increased refrigerant flow through expansion valve 74. This action allows the surface of evaporator 76 to be maintained below the dew point of ambient air at a wide range of ambient air temperatures. In operation, air flowing through the evaporator 76 gives up its heat, thereby causing water vapor within the air to condense on the surface of evaporator 76 and fall into a collecting tray 90.

[0054] Water-cooled subcooler 72 allows additional refrigerant to be stored within the refrigerant path, such that it is readily available for use when conditions require additional refrigerant as noted above. By maintaining collected water in collecting tray 90, water-cooled subcooler 72 is submerged in water that has been recently condensed, and cooled to a temperature at or near to the temperature of evaporator 76. Water at this cooler temperature increases the efficiency of the water-cooled subcooler.

[0055] The refrigerant flow also includes a path through an auxiliary evaporator 92 via a second expansion valve 94. In operation, this allows some compressed refrigerant to bypass around the evaporator 76, thereby flowing through auxiliary evaporator 92. This portion of the refrigeration system may be referred to as a second branch portion. Auxiliary evaporator 92 may have any suitable shape, including cooled, unheated or convoluted, and surrounds chilled water vessel 96. Water inside chilled water vessel 96 is thereby cooled, and the evaporated refrigerant enters compressor 124 to begin the refrigeration cycle again.

[0056] The water extracted from ambient air flows through the water production system shown in FIG. 3 as follows. Water collects in collecting tray 90, and a drain tube 98 may be arranged within collecting tray 90. Accordingly, after the water rises to a predetermined level that is sufficient to submerge the water-cooled subcooler 72, additional water drains through drain tube 98 and into a water tank 100. An ozone diffuser 102 is supplied with ozone by an ozonator 104, to ozonate the water in water tank 100, which tends to purify it.

[0057] When a primary water collection vessel 100 is full, a thermostat or other temperature sensor 216, which senses temperature in chilled water vessel 96, may signal a first switch or controller 220 to turn on compressor 124, and may signal a second controller 218 to turn off an air movement device such as a fan or coil 84. When the fan 84 is off, a first and second evaporator 76 and 92 are under a decreased load, thereby lowering the pressure and temperature of the refrigerant within the refrigeration circuit. The compressor 124 sends the refrigerant to the second evaporator 92 at a cold water vessel 96 to chill the water. The use of the sensor 216 to control the blower 84 allows the dual use of the water-making components to provide refrigeration for the chilled water vessel 96 when the primary collection vessel 100 is full.

[0058] When the primary water vessel 100 is full, float switch 214 may shut off the water-producing apparatus so that water is no longer produced, but a refrigeration mode or "chilling cycle" is enabled. During this chilling cycle, sensor 216 in the secondary vessel 96 signals the first controller 220 to run the compressor 124, and signals the second controller 218 not to run the fan 84. The result is that the secondary evaporator 92 chills the secondary water vessel 96 without the first evaporator 76 producing more drinking water.
Any suitable type of sensor may be used. For example, a first sensor may be provided to determine an amount of water in the primary water vessel, and a switch may shut off the air movement device when the amount of water in the first water vessel is at least equal to a predetermined amount. This predetermined amount may be equal to that which fills the primary water vessel, or another suitable amount. The switch may also shut off the refrigeration system when the amount of water in the primary water vessel is at least equal to the predetermined amount.

The sensor 216 may send a temperature indication to a controller, e.g., a microprocessor, which determines the appropriate time to turn the compressor on or off, as well as when to turn the blower 84 off. This control allows the water-producing apparatus to chill the water without freezing the water and/or any refrigeration components. For example, when the apparatus is in a water-producing mode, the blower 84 and the compressor 124 are both on. However, when the apparatus is operating to refrigerate the water, the compressor 124 is on, but the blower 84 is off.

The controller may also cycle the blower between on and off while chilling the water to ensure that when water is dispensed, it is subsequently replaced by ambient water. A second sensor may also be provided to determine an amount of water in the primary collection vessel 100 or the secondary water vessel 96, and a switch may then activate both the refrigeration system including the compressor 124 and the air movement device or fan 84, when the amount of water in a water vessel is at most equal to a predetermined amount. This predetermined amount may be approximately equal to a water vessel being empty, or another suitable amount such as for example half of a water vessel’s capacity.

Temperature sensor 216 may be provided to monitor the temperature of water in the chilled water vessel 96, such that when it falls below a predetermined threshold, the controller also turns the compressor 124 off to ensure that the water does not freeze. This predetermined threshold temperature may be substantially equal to the freezing temperature of liquid water, or may be another temperature.

A pick-up tube 106 is positioned within water tank 100, such that water can be extracted from water tank 100 and pumped by a water pump 108 into chilled water vessel 96, through a filter 110, and out either a cold water faucet 112 or a hot water faucet 114. Filter 110 can be, for example, a coal carbon filter. Water destined for hot water faucet 114 is first collected in a hot water vessel and heated by a heater 118. Heater 118 may be an electric heater controlled by a thermostat (not shown).

As is shown in FIG. 3, the water path of the water production system also includes a return path back to water tank 100 through water return line 120 and valve 122. Valve 122 may be a solenoid or other electrically-operated valve. When there is little or no demand for water from the cold water faucet 112 and hot water faucet 114, valve 122 may be opened so that water may be circulated by water pump 108 from water tank 100, through chilled water vessel 96 and back into water tank 100. This recirculation facilitates the ozonating process and resists bacteria formation in the plumbing lines from water tank 100 to the faucets 112 and 114. Valve 122 can be controlled by a microcontroller or other processor which monitors water demand, for example, by monitoring the water pressure on the outlet side of the pump 108. Other arrangements for monitoring the water pressure to thereby control the valve 122 are also contemplated, and of course the invention is not limited solely to the arrangement described above.

Water production systems of the present invention may also provide an air duct with one or more ports, including an entry port and an exit port. An air movement device may be a fan disposed within the air duct, operable to draw air through the air duct.

If a specific embodiment defines an air duct, an intermediate port may be provided between the entry port and exit port, such that the air duct defines a first and second air flow path. The first air flow path may proceed sequentially through the entry port, evaporator, condenser, and exit port. In contrast, the second air flow path may proceed sequentially through the intermediate port, condenser, and exit port, thus bypassing the evaporator. In other words, with the intermediate port being positioned between the evaporator and condenser, air can enter the air duct: (i) through the entry port and evaporator, and (ii) through the intermediate port, bypassing the evaporator. The air movement device in such embodiments is capable of moving air through the air duct along the first and second air flow paths.

For example, FIGS. 4-9 depict a water production system defining a rectangular air duct having entry ports, intermediate ports, and exit ports. The exit port is positioned at one end of the air duct, and the fan is positioned near the exit port. Water production systems according to the present invention may have one or more bypass ports that remain open, or may be selectively opened and closed, either in a binary or selectively adjustable fashion. The water production system 200 of FIGS. 4-9 has four intermediate ports 202a-d (referred to collectively herein as “intermediate port 202”) defined on the top between each of four evaporators 204a-d (referred to collectively herein as “evaporator 204”) and four condensers 206a-d (referred to collectively herein as “condenser 206”), and at least four additional intermediate ports 208a-d (referred to collectively herein as “additional intermediate port 208”) are defined on both sides of each pair of evaporators 204 and condensers 206. A corresponding set of four water-cooled subcoolers 210a-d (referred to collectively herein as “subcooler 210”) is positioned within four water basins 212a-d (referred to collectively herein as “water basin 212”), and below each evaporator 204.

While conventional refrigeration systems may be optimized for cooling the air in a chamber, water production systems are optimized for production of water. Accordingly, one or more water-cooled subcoolers of the present invention may be desirable to increase the efficiency of the water production system.

In embodiments having more than one evaporator and condenser, it may also be desirable to connect the evaporators to the refrigeration system in parallel, and yet connect the condensers to the refrigeration system in series. In this case, the refrigeration system may be arranged to cause the refrigerant to exit the first condenser in a gaseous state, and to exit the second condenser in a liquid state, such that the first condenser acts as a de-superheater.

Water production systems of the present invention may also be provided with an ice sensor capable of sensing ice buildup on an evaporator, and a switch coupled with the ice sensor to shut off the refrigeration system when ice is present, with the air movement device remaining in operation.

In operation of the water production systems of the present invention, a method of extracting water from air may
include, for example, providing an air duct having an entry port, an intermediate port, and an exit port; providing an air movement device; and providing a refrigeration system including a cooling element. The method may also include operating the air movement device to cause air to flow along a first and second air flow path. The first flow path may be into the entry port, through the cooling element, and out the exit port, while the second flow path may be into the intermediate port, and out the exit port, thus bypassing the cooling element. The method according to the present invention may further include operating the refrigeration system to cause the cooling element to maintain a temperature of at most a dew point of air contacting the cooling element. The present invention may also include condensing liquid water on an exterior surface of the cooling element, and collecting the liquid water.

In the method of the present invention, a bypass valve may further be provided, and may also include determining a temperature of the air, opening the bypass valve when the temperature exceeds a selected temperature, and closing the bypass valve when the temperature falls below the selected temperature. The method of the present invention may also include adjusting one or more bypass valves in response to a variety of conditions, inputs or sensors, including for example a thermometer, clock, timer, humidity sensor, rain sensor, light sensor, etc.

In a specific example embodiment of the present invention, a water production system may be provided as shown FIGS. 4-9, with various components being selected as follows: two matching refrigeration systems, each having a 5 hp compressor, a pair of evaporators with an air flow capacity of 100 pounds of air per minute, a pair of water-cooled subcoolers, a pair of expansion valves, and a pair of condensers with an air flow capacity of 200 pounds of air per minute. The fan was selected having a capacity of 200 pounds of air per minute, and adjustable bypass valves were provided with a controller set to open them above an ambient air temperature selected at 78 degrees Fahrenheit, or 25.6 degrees Celsius. The resulting example embodiment produced approximately 0.5 liters of water per minute.

Another embodiment of the present invention may involve constructing a water production system with tubing and other components of one or more materials which resist accumulation of bacteria. Examples may include conduits from a water inlet to a pump inlet, from a pump outlet to a water chiller component, and from a chiller component to a water filter. In other words, all plumbing pieces contacting the collected water may be composed of tubing which resists contamination, for example HPC bacteria. One possible material that may exhibit such an advantage is copper, and using copper tubing may be advantageous.

Several advantages may be achieved with the present invention, including for example enhanced efficiency, lowering the amount of energy used to produce a specific amount of water when operating the water production system. Another advantage of the present invention includes broadening the possible environments, geographical areas, weather conditions, and times of day when the water production system of the present invention may be used effectively and efficiently.

It should be understood that an unlimited number of configurations for the present invention could be realized. The foregoing discussion describes merely exemplary embodiments illustrating the principles of the present invention, the scope of which is recited in the following claims. In addition, unless otherwise stated, all of the accompanying drawings are not to scale. Those skilled in the art will readily recognize from the description, claims, and drawings that numerous changes and modifications can be made without departing from the spirit and scope of the invention.

What is claimed is:

1. An apparatus for extracting water from air, the apparatus comprising:
   a refrigeration system defining a closed-loop refrigerant path, the refrigeration system including:
   a main portion;
   a first branch portion; and
   a second branch portion, the first branch portion and the second branch portion each having an entrance and an exit in fluid communication with the main portion;
   the first branch portion including a first evaporator operable at a temperature of at most a dew point of air contacting the first evaporator to cause liquid water to condense on an exterior surface of the first evaporator;
   the second branch portion including a second evaporator;
   a first water vessel positioned proximate to the first evaporator for collecting water from the exterior surface of the first evaporator;
   a second water vessel positioned proximate to the second evaporator for holding water chilled by the second evaporator; and
   a conduit for transporting water from the first water vessel to the second water vessel.

2. The apparatus according to claim 1, wherein the second evaporator operates at a temperature less than the ambient air temperature.

3. The apparatus according to claim 1, wherein the first water vessel is positioned below the first evaporator to collect the water dripping from the exterior surface of the first evaporator.

4. The apparatus according to claim 1, wherein the refrigeration system further comprises:
   a compressor in the main portion of the closed loop refrigerant path;
   a condenser in the main portion of the closed loop refrigerant path;
   a first expansion valve in the first branch portion of the closed loop refrigerant path; and
   a second expansion valve in the second branch portion of the closed loop refrigerant path.

5. The apparatus according to claim 4, further comprising a refrigerant in the closed loop refrigerant path, the refrigerant passing sequentially during operation from the compressor to the condenser, to both of the first and second branch portions in parallel, thereafter returning to the compressor.

6. The apparatus according to claim 1, wherein the refrigeration system further comprises an air movement device for moving air over the exterior surface of the first evaporator.

7. The apparatus according to claim 1, further comprising:
   a first sensor, the first sensor being used to determine an amount of water in the first water vessel; and
   a switch operable to shut off the air movement device when the amount of water in the first water vessel is at least equal to a predetermined amount.
8. The apparatus according to claim 7, wherein the switch is further operable to shut off the refrigeration system when the amount of water in the first water vessel is at least equal to the predetermined amount.

9. The apparatus according to claim 7, further comprising: a second sensor, the second sensor being used to determine a temperature of water in the second water vessel; and a switch to activate the refrigeration system when the temperature of water in the second water vessel is less than a predetermined temperature.

10. The apparatus according to claim 9, further comprising: a switch to shut off the refrigeration system when the temperature of water in the second water vessel is not more than a second predetermined temperature.

11. The apparatus according to claim 10, wherein the predetermined temperature substantially equals the freezing temperature of liquid water.

12. The apparatus according to claim 1, further comprising an ozonator and an ozone diffuser for purifying liquid water in the second water vessel.

13. A method of extracting water from air using a water production system, the water production system including an air movement device, a first water vessel, a second water vessel and a refrigeration system having a first cooling element and a second cooling element, the method comprising: operating the air movement device to cause air to flow and contact the first cooling element; operating the refrigeration system to: cause the first cooling element to have a temperature of at most a dew point of air contacting the first cooling element during operation; and cause the second cooling element to have a temperature less than the temperature of a fluid contacting the second cooling element during operation; condensing liquid water from the air on an exterior surface of the first cooling element; collecting the water in the first water vessel; moving a portion of the water from the first water vessel into the second water vessel; cooling the water in the second water vessel using the second cooling element; and shutting off the air movement device if an amount of water in the first water vessel exceeds a predetermined amount.

14. The method according to claim 13, further comprising: shutting off the refrigeration system if a temperature of water in the second water vessel is not greater than substantially to the freezing temperature of water.

15. The method according to claim 13, further comprising: resuming operation of the air movement device if an amount of water in the first water vessel is less than a predetermined amount.

16. The method according to claim 13, wherein the fluid contacting the second cooling element is air.

17. The method according to claim 13, wherein the fluid contacting the second cooling element is water in the second water vessel.

18. A method of extracting water from air using a water production system, the water production system including an air movement device, a first water vessel, a second water vessel and a refrigeration system having a first cooling element and a second cooling element, wherein the method comprises: monitoring an amount of water in the first water vessel; monitoring a temperature of water in the second water vessel; and operating the air movement device to cause air to flow and contact the first cooling element when the amount of water in at least one of the first water vessel and the second water vessel is below a predetermined amount; operating the refrigeration system to: cause the first cooling element to operate at a temperature of at most a dew point of air contacting the first cooling element; cause the second cooling element to refrigerate the second water vessel; condensing liquid water from the air on an exterior surface of the first cooling element; collecting the water in the first water vessel; moving a portion of the water from the first water vessel into the second water vessel when the amount of water in the first water vessel exceeds a predetermined amount.

19. The method according to claim 18, further comprising: operating the air movement device and shutting off the refrigeration system if a temperature of water in the second water vessel is not greater than substantially the freezing temperature of water.

20. The method according to claim 18, wherein shutting off the air movement device reduces a rate of condensation of liquid water on the first cooling element.